GEOLOGY AND GEOMORPHOLOGY OF THE MURRAY RIVER REGION BETWEEN MILDURA AND RENMARK, AUSTRALIA

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Introduction

"To a person uninstructed in natural history, his country or seaside is a walk through a gallery filled with wonderful works of art, nine-tenths of which have their faces turned to the wall". So said T. H. Huxley. Although instructed in natural history, we found the area studied in this *Memoir* so dry in its time of deep drought when we first went there, so flat, and so unvaried compared with other research areas, that we wondered what story it had to yield. However, it was judged that this country, like all others scientists have investigated, would have a useful and fascinating story when it had been deciphered. So it proved to be.

The Research Project

The flattest continent in the world is Australia, and it is also the driest. Put these two facts together, and it can be inferred that the major river system is somewhat unusual. Such the Murray/Darling system certainly is, as the sequel clearly shows. The river tract between Mildura and Renmark is a significant part of this system. Here the Darling River and the Darling Anabranch enter the Murray. Here the valley is 15 to 30 km wide, then suddenly narrows to five kilometers, so making the proposed Chowilla Dam possible. So flat is this area that, if the dam is completed, 1370 km^2 will be inundated. Lake Victoria, a giant billabong (oxbow) system, is on an anabranch formed by the Frenchman's Creek and the Rufus River. It has acted as a massive sand trap, so that a large dune tract lies on its E. bank, emplaced and remodelled over 20,000 years at least by the persistent W. winds of that country. Under natural conditions Lake Victoria is half dry (except in flood time) being an abandoned part of the course of the Murray. At present it is used as a water storage (11,200 hectares).

This Research Project was triggered by the commencement of building operations at the Chowilla Dam site. The Trustees thought that this little-known area where three States meet should be investigated before it was inundated. The undertaking was therefore a salvage one, but on a scale not attempted in Australia before. The area to be flooded plus a necessary marginal area gave a total of 2600 km^2 to be studied. As a result, the study had to be of a reconnaissance nature, with more detailed attention to significant sites. No account of the geomorphology, geology and archaeology of the area has been given before, but there are numerous incidental references in a wide literature; an attempt has been made to provide a bibliography of the more important references. The stated aim of the Project was to collect data and materials that would have been lost as a result of the construction of the dam, but the ultimate aim was to achieve a fundamental understanding of this tract of country—how it came into existence and what the present processes are. A contribution to this aim is set out in this *Memoir*.

The Project was successful beyond expectation. The fundamental geology is of wide application. The palaeontology is making important contributions to knowledge, e.g. Late Pliocene(?) fish remains include *Neoceratodus*, and the skeletons of extinct marsupials make possible the indentification of post-skeletal material previously not referable to any species. Some skeletons were still articulated. The archaeology reveals middens back to 18,000 years ago. The Aborigines of the area were very conservative and kept to their old core/flake culture, eschewing the new blade culture with hafted tools. An Aboriginal skeleton with gypsum widow's cap proves use of this device back to c. 750 years at least. The palaeoclimatology permits recognition of the beginning of the present aridity.

This extensive research operation would not have been possible without supporting funds. The William Buckland Foundation made the chief contributions, and the Sunshine Foundation also contributed. E. D. Gill received a grant from the Nuffield Foundation towards the geological research. Sir Robert Blackwood, Chairman of Trustees (now President of the Council under a new Act), took a special interest in the Project, and joined most of the field expeditions; he has presented in this *Memoir* his work with K. N. G. Simpson on the excavation of Aboriginal skeletons. The funds provided by the Foundations made it possible to employ Mr. K. N. G. Simpson as Field Officer. We are grateful to the scientists who have contributed papers to this *Memoir,* and to those whose assistance is acknowledged in the appropriate places. Mr. G. Douglas of Werrimul gave us a great deal of assistance in the field. We are much indebted to the people on the land. Their hospitality, their assistance when needed, and their fund of local information greatly assisted us. Through their help we were able to achieve much more than would otherwise have been possible.

An account of this investigation was given in ten radio lectures requested by the Australian Broadcasting Commission. These were later published under the title "Rivers of History" (Gill 1970).

Major river system of the flattest continent

Our planet has six continents of which two are islands—Australia and Antarctica. In average elevation above the sea, Antarctica is the highest and Australia the lowest. More than half of Australia is below 300 m, and only about five per cent is above 600 m. Australia is the flattest continent in the world, which fact has a profound effect on its major river-system, the Murray/Darling. The names of the two rivers are commonly linked in this manner because the branch river (Darling) is 160 km longer than the main river (Murray), which is 2570 km long.

Moreover, Australia is the world's driest continent with 75 per cent of its land surface arid or semi-arid. That Australia is so flat and so dry, explains many of the unusual features of the Murray/Darling. Both rivers rise in high rainfall areas of the Great Dividing Range. The Murray rises in the temperate zone on the Kosciusko Plateau. The Darling rises in the subtropical to tropical areas further north.

After only 300 km or so these rivers flow with a very low grade (because the continent is so flat) through 1500-2500 km of river course which contributes little or no water (because the continent is so dry). Along the course of the Darling River from the Queensland border to where it joins the Murray River at Wentworth is about 2170 km over which it falls only 120 m. Thus over a long distance the remarkably low mean declivity of 5·6 cm per km is maintained.

The Murray River at Albury has a fall of 14·2 cm per km which is reduced to the minimum of about 1·6 cm per km for the last 160 km. The water at Albury takes a month to reach the sea. That in the headwaters of the Darling takes two months or more to reach its conjunction with the Murray at Wentworth. Water from the Dartmouth dam being constructed on the Mitta Mitta River will take six to eight weeks to reach S. Australia. The Murray/Darling system has an average annual run-off of only 15,000 m^3 per km^2. The Yangtze-Kiang River in China has a run-off of $1{\cdot}19 \times 10^6$ m^3 per km^2 per annum.

In the area under study between Mildura (Victoria) and Renmark (S. Australia) the valley of the Murray River (Pl. 1) widens to 32 km, including Lake Victoria which is a former meander system, then narrows to 4·8 km at the Chowilla Dam site. Further downstream it narrows to 1·6 km. It is a significant part of the course because here the Darling and its Anabranch join the Murray, the effects of tectonics on the river course can be studied, the cliffs reveal the essential stratigraphy, many fossil localities have been discovered, and Lake

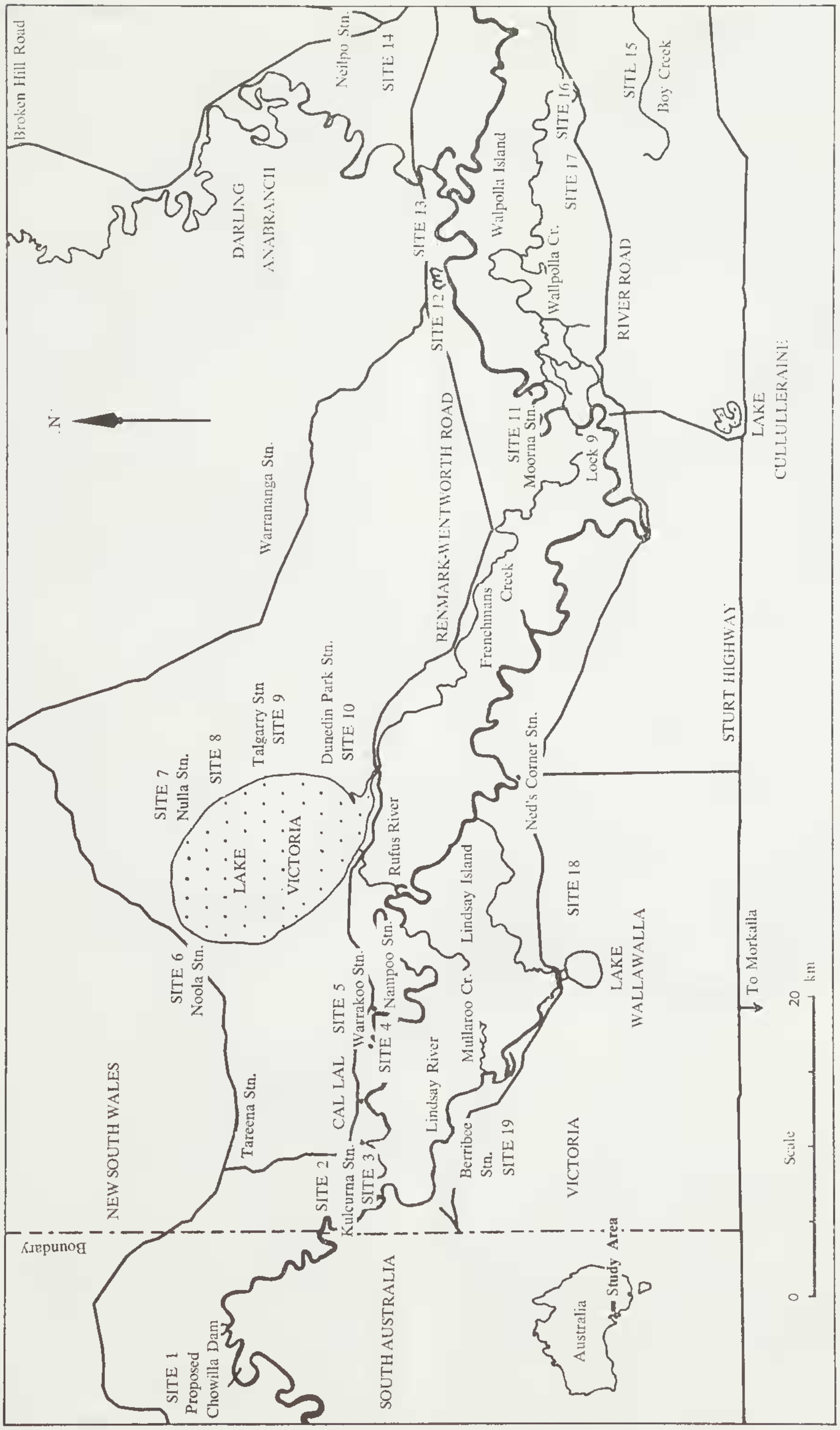


Fig. 1—Locality map of study area.

Victoria with its large lunette on the E. side constitutes a phenomenon of unusual interest.

For much of its course the substrate of the river systems is clay (Browne 1934). If the Darling and the Murray ran into deep sandy country they could well be swallowed up, because the volume of water carried is relatively small, and the evaporation is high (~1·8 m p.a.). The Darling travels in what is virtually an aqueduct of clay which prevents loss by soakage. Some irrigation channels in sandy areas lose 80-90 per cent by soakage, which gives an idea of what could happen to the river waters if they had a similar substrate. In the area of study the river flows chiefly in clay or clayey sand that acts as an aquiclude. The Chowilla Sand is clean and can act as an aquifer, but it is a channel sand, and so is limited in capacity. I have seen no springs emerging from it. Probably the Blanchetown Clay and other clayey formations prevent water reaching it from the surface, while the complex interdigitation of formations limits the distance water can travel in the channel sands.

Apart from the meanders, the river course directions are curious and call for explanation. To understand this part of river-history, it is necessary to consider the geology of the area. Apart from their courses in the mountains and foothills, the Murray and Darling Rivers run over a deep sedimentary basin—the Murray Basin. This will now be considered, because the geological history is such that what happens at depth influences what happens at the surface.

Drainage basins

In the E. half of Australia there are two large drainage basins—the Lake Eyre and the Murray. The Lake Eyre drainage basin is the largest in Australia, and is large by world standards, being some 1,300,000 km² in extent. Although so large a basin, it drains very little water. Because the continent is so flat, the declivities are low, and there are no high mountains round the edge of the basin. Because Australia is so dry, very little rain falls (the isohyets range from 12 to 25 cm only) and having flat sandy terrains to cross with a very high evaporation, the water seldom reaches Lake Eyre. Only once in living memory (Mawson 1950, Bonython 1955) has Lake Eyre been filled. Lake Eyre occupies a very shallow depression a little below sealevel. What would be a small or negligible flexure on most terrains, here created a huge drainage basin because if the flatness of the country.

To the SE. is the smaller Murray Basin (Fenner 1934), which can be defined approximately by the 180 m contour. A wide northern part is occupied by the Darling River and its tributaries. The Darling and Paroo Rivers meet at Wilcannia and pass through a comparatively narrow zone which has been named the Cobar Neck, being W. of that city. The basin then widens again to comprehend the Murray River and its tributaries along with the Darling River from the N. This is often referred to as the Murray/Darling riverine plain. The area discussed in this *Memoir* is more or less in the middle of this plain.

The Murray and Darling begin in the Great Dividing Range with a strongly dendritic stream pattern (Taylor 1914). Because the inland is semi-arid, the tributaries rapidly disappear. In the N. the Darling is the only continually flowing stream. In the S., no tributary of consequence enters the Murray after the Darling joins it at Wentworth. The Murray and Darling Rivers may thus be considered gutters that drain the waters of the W. side of the Dividing Range across the semi-arid inland to reach the sea to the SW.

Sedimentary basins

The surficial drainage areas of the present are directly related to the sedimentary basins of the past. In E. Australia there are two important sedimentary basins—the Great Artesian Basin to the N. and the Murray Basin in the S. There is a narrow connecting area W. of Cobar as there is in the present drainage basins. It is called the Darling Corridor by Devine and Power (1970). While the Murray Basin is a unit, the Great Artesian Basin has a number of sub-basins such as the Carpentaria Basin on the Gulf of that name, and the Surat Basin in E. Queensland which has been a source of oil. The Great Artesian Basin is chiefly of Mesozoic

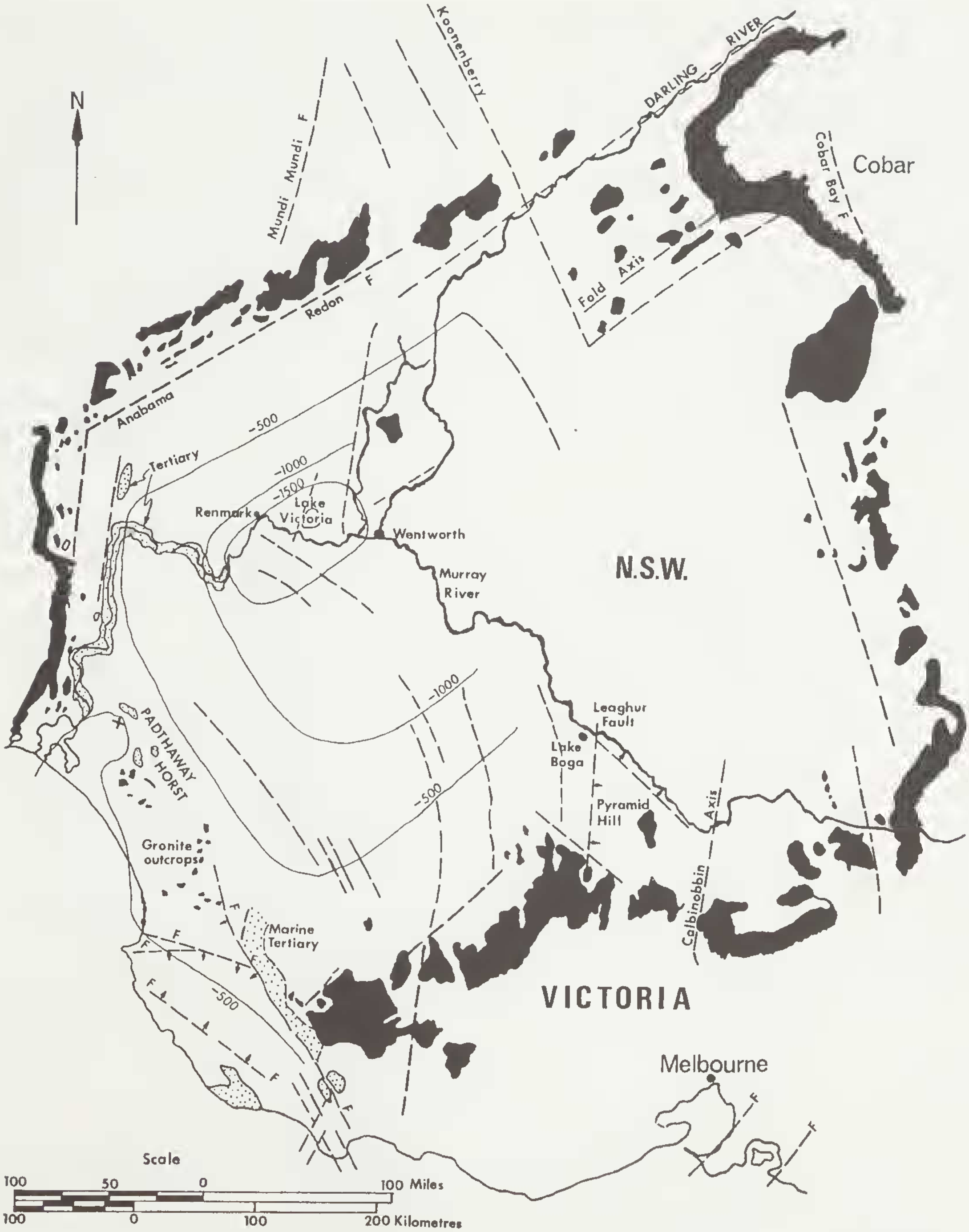


Fig. 2—The structure of the Murray Basin (after Hills) with some additional information.

strata, while the Murray Basin consists of Mesozoic and Cainozoic strata. Although the Murray Basin appears small beside the Great Artesian Basin, it is nevertheless quite extensive, being about twice the area of France.

Murray framed sedimentary basin

In outcrop, the Cainozoic beds of the Murray Basin present a rounded structure, as may be seen in the 1960 Tectonic Map of Australia published by the Bureau of Mineral Resources. However, the fundamental bedrock structure is quadrate, as shown by Hills (1956) whose map is reproduced as Fig. 2 with the addition of some later information.

The Australian Oil and Gas Corporation Limited sank bores at Renmark, Lake Victoria, and Wentworth. With their permission, Fig. 3 is published containing the information obtained therefrom. The palaeontologist who reported for the Corporation was able to identify all strata with some certainty as high as the Bookpurnong Beds. These are probably Cheltenhamian (Uppermost Miocene) and those reported in the Lake Victoria bore are no doubt the same horizon as that in a deep well at Tareena Station (Tate 1899) on the N. side of the Murray River between the S. Australian border and Lake Victoria (now part of Kulcurna Station). Tate was uncertain of the age of the occurrence, but compared the fauna with

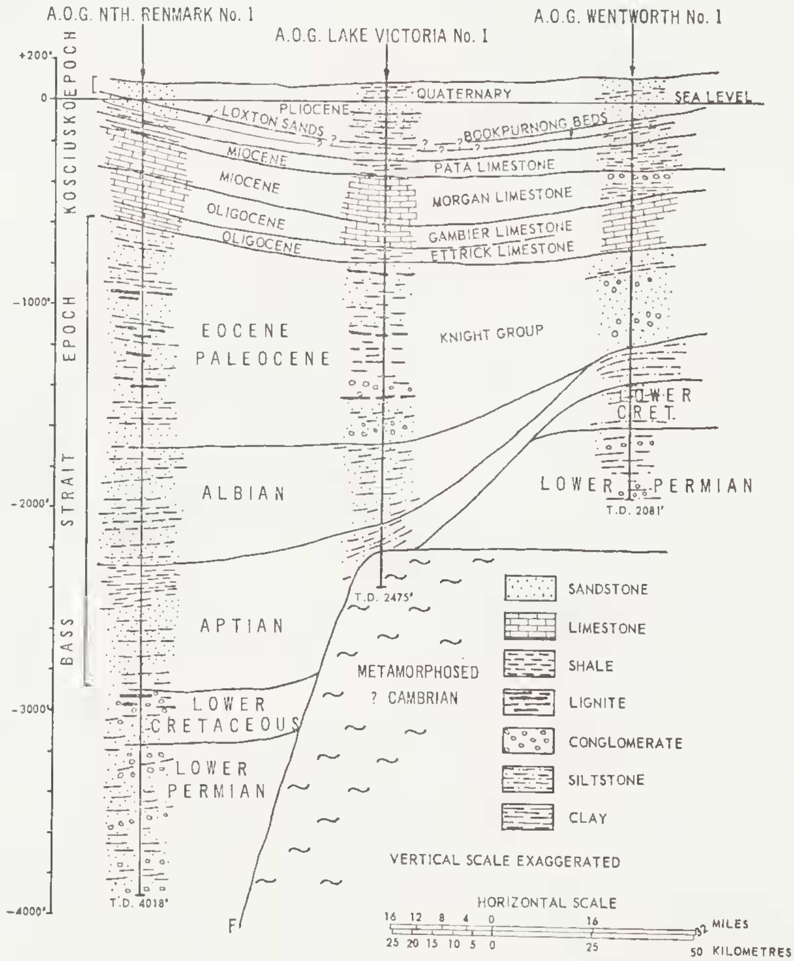


Fig. 3—Geological section between Renmark and Wentworth by courtesy of Australian Oil and Gas, with some adaptations.

that at Beaumaris, Victoria, which is the type locality for the Cheltenhamian Stage. Mr. T. A. Darragh, Curator of Fossils of this Museum, considers that the fauna is probably Cheltenhamian, pointing out that *Pelicaria coronata* is one of the characteristic species obtained from the well. At both Beaumaris and Tareena Station, the sediments are nearshore marine in ecology.

At the Chowilla Dam site, Loxton Sands (Firman 1966) have been proved, and it may be that at Tareena Station and Lake Victoria they lie between the Cheltenhamian marine bed and the Parilla Sand (which outcrops along the Murray River and up Salt Creek), but this has not been established. Presumably, the calcareous marine bed was at the base of the Tareena well, while the Loxton Sands or equivalent provided the aquifer (if any). Certainly the clayey Parilla Sand at or near the surface would act as an aquiclude.

The stratigraphy revealed by the bores of Fig. 3 shows:

1. A succession of alternating marine and non-marine phases.
2. A massive fault in the basement rocks, with a throw of the order of 600 m demonstrated, but the exact amount of dislocation unknown. The A. O. G. geophysicists traced this structure for some 24 km NE. of the Lake Victoria well site. The fault is a major one, and so is here named The Lake Victoria Fault. Its orientation is that of the Bouger anomaly contours (Bureau of Mineral Resources, Geology and Geophysics plans G. 239/1/1 and 2/1).
3. On the interpretation given in Fig. 3, movement began in the Aptian. As the undifferentiated Lower Cretaceous is of the same thickness on both sides of the fault, it is concluded that displacement occurred after its deposition.
4. The earth movements have been slow. Kulp (1961) gives the beginning of the Cretaceous as 135 m.y. and the beginning of the Albian as 120 m.y. It has thus taken in excess of 120 m.y. to build this part of the Murray sedimentary basin.
5. The rate of movement has varied with time. As the relative thicknesses of the formations indicate, movements were more rapid in the Aptian-Eocene and in the post-Miocene. These belong to the Bass Strait (Gill 1964, p. 347) and the Kosciusko Epochs (Andrews 1910) respectively. As registered by the movements in this area, the Bass Strait Epoch lasted for some 70 m.y., while the Kosciusko Epoch has existed for only about 15 m.y. However, the latter epoch may be considered as still in progress. The present may be a lull in a longer period of movements. The gap between the Bass Strait and Kosciusko epochs in the Murray Basin is about 45 m.y.

Basin Frame

The frame of older rocks round the basin consists chiefly of the Adelaide Geosyncline formations on the W. and the Tasman Geosyncline formations on the E. The former consists essentially of Precambrian to Cambrian rocks, while the latter consists chiefly of Lower and Middle Palaeozoic rocks. Their structural relationships are shown on the 1971 Tectonic Map of Australia. These geosynclines provide also the frame rocks to the N. To the SW. is the opening by which the sea reached the Murray Basin, but this is complicated by a horst, the Pinnaroo Block. Along the Padthaway Ridge are highs of granitic rocks that formed an archipelago in the Tertiary sea. In other words, the horst formed a sill over which the sea passed into the basin.

Tectonics

The Cainozoic tectonics of Australia are weak, contrasting with the powerful movements that characterize New Guinea to the N. and New Zealand to the E. The rates of movement contrast strongly. Thus in the middle of the Murray Basin depression (Fig. 3) the average rate of sinking since the beginning of the Cretaceous has been ~1 m per 120,000 y. whereas average rates calculated for various lengths of time back into the Cainozoic are in New Zealand ~1 m per 100 y, and in New

Guinea from 1 m in 5,000 y to 1 m in 88 y (Gill 1972). During the Cainozoic, the tectonic movements were in the form of broad warps that deepened basins and flexed up marginal low-mountain areas such as the Mt. Lofty Mts. on the W. of the Murray Basin, and the Great Dividing Range on the E. and S.

1. *Constancy of Tectonic Pattern*

As a result of the mildness of the movements, no change in the tectonic pattern of the study area has occurred since the commencement of the Cretaceous Period. Moreover, ancient faults of Palaeozoic, or greater age (such as the Lake Victoria Fault) have continued to make their influence felt (cf. Firman 1970), because the small movements on these lineaments are significant on a surface where slopes are so slight. The basin is completely filled with sediments and so the surface is about as flat as it can be. The only steep slopes are the banks of the river tract, which has been incised ~36 m (Pl. 2).

2. *Geomorphic Control by Deep-seated Lineaments*

These palimpsest tectonics, as they might justifiably be named, are critical to the understanding of this area. The description of the formation of Lake Victoria later in this contribution illustrates this well. The River Murray in the area of study flows through a terrain of E-W dunes, but those to the N. appear to be an older system than those to the S., so some tectonic boundary may be involved. N. of the river, the Blanchetown Clay typically outcrops at or near the surface, so that water tanks can be excavated in it. The sand supply is therefore limited. To the S., the country is more sandy, and the irrigation channels in some areas lose most of their water by soakage.

Hills (1956a) states that "tectonic significance must be attached to every stretch of the River Murray, and that from trends alone a clear indication of structure—the nature requiring to be investigated in each case—is provided". Johns and Lawrence (1964) with reference to that part of Murray Basin in NW. Victoria state, "It appears that movement along ancient lines of weakness in two or three directional trends (approximately NW., NE. and N.) within the basement rocks, have been dominant in the formation of the basin". Hills (1956b) has called this "resurgent tectonics".

3. *Strong Influence of Small Faults in Flat Country*

Displacement in the Cadell fault near Echuca on the Murray River (Harris 1939), although with a throw of a maximum of only 12m, caused a major diversion of the river. The fault is across the river (N.-S.) with a tilt downstream to the W. The main flow of the Murray River was diverted S. along the fault line, to join the Goulburn R. above Echuca, thus taking over some 80 km of the course of that river. Some water flows N. along the N. arm of the fault line to Deniliquin, then turns W. as the Edward River to form an anabranch fed through the offtakes in the low-lying forest areas between Tocumwal and Echuca. So this minor fault, because of the flatness of the country, strongly diverted Australia's largest river, and created the Echuca Depression in which a lake was formed, and from the sandy beaches of which the Bama Sandhills were built. The N. and S. divergences of the Murray River join up to the W. again, thus surrounding the triangular Cadell Tilt Block. In the mountainous upper reaches of the Murray, the development of a fault across the river with a final displacement of 12 m. would have a negligible effect, but on the flat surface of the sedimentary basin, it caused a major dislocation (Bowler and Harford 1963, Bowler 1967).

The continuing influence of extremely old lineaments to the present time is illustrated by the Berridale Wrench Fault (Lambert and White 1965), the main movement of which is dated Early to Middle Devonian, with continuing minor dislocation during the Tertiary, while "seismic activity . . . indicates possible recent movement." Hills (1961) has commented that "in Australia the results indicate long-continued activity along ancient lines of weakness and considerable evidence for greater mobility of the cratonic units than is normally attributed to them. Lineaments and blocks are prominent and many of the geo-

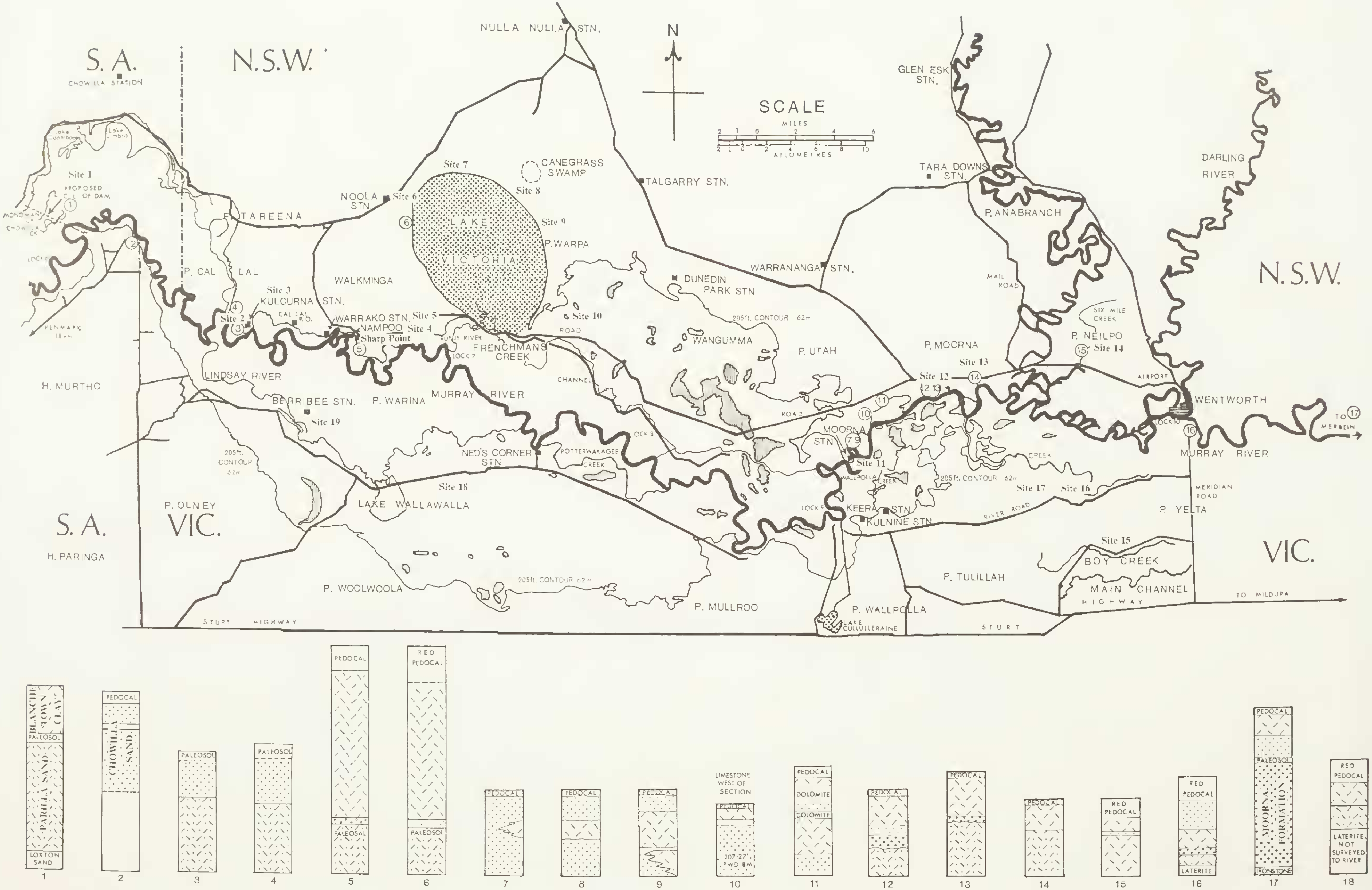


Fig. 4—Map of project study area, with a series of measured stratigraphic sections. The numbers below the sections appear in circles at the sites on the map above. The 205 ft. (62 m) contour is the level to which flooding by the Chowilla Dam was designed. Such contours are on the S.A. datum of M.S.L. Adelaide = 106·88 ft. Lake Wallawalla is dry, and Lake Cullulleraine is an irrigation storage. Only sections 1-2, 5-6 and 17 reach the local plateau level. Behind the other sections, the terrain rises, and in many instances Blanchetown Clay was proved there.

Note that the downwarp in this area from the Pinnaroo Block to the W. causes the Loxton Sand to disappear below river level as one moves E., and then similarly the Parilla Sand. The latter reappears at Paringi far to the E. In the Lake Victoria syncline, the Moorna Formation is intercalated below the Blanchetown Clay/Chowilla Sand complex. The vertically hatched areas on the river floodplain are Rufus Formation. The base of each section is river level, while No. 6 on Lake Victoria is at the level of Lock 9, from which the lake is filled. H (in S.A.) = Hundred; P (in Victoria) = Parish. Section 18 (not on map) is from Paringi, SE. of Mildura.

logical basins are framed by lineaments". As already indicated, this is true of the Murray Basin.

4. *Structure Pattern at Surface*

Firman (1970) has recorded a faint pattern of structural elements which he recognized from low-flying light aircraft and mapped from aerial mosaics. The results were related to geophysical and geologic information. They were used to define the Pinnaroo Block (Firman 1966).

5. *Degree of Tectonic Control of Sedimentation*

Without subscribing to a complete theory of tectonic control of sedimentation (e.g. as discussed by Crook 1967), it can be stated as fact that the tectonic style of the area affects the nature of the sedimentation. On first studying the area, I was impressed with the almost universal occurrence of fine sands—in the Parilla Sand, the sandy phases of the Blanchetown Clay, the Chowilla sand (although a channel deposit), the various Quaternary riverine and dune systems, and much of the Moorna Formation. It was with some surprise therefore that I came upon the ossiferous gravelly sand of a channel deposit in the Moorna Formation at Fishermans Cliff, on Moorna Station. Even the sediments of the present Murray River, rejuvenated by incision of a course round the Pinnaroo Block, are fine clayey sands on the floodplains as seen in the red outliers (relicts of a Pleistocene terrace with giant marsupial remains, here named the Rufus Formation) and the Coonambidgal Formation. Washed sands characterize the channels. This general fineness of sediment is a function of the low dynamics of the streams which in turn is due to their exceptionally low grades, a result of the mild tectonics. See grain size analyses in section on *sedimentation*.

The tectonic uplift of the Pinnaroo Block dammed the Murray River and brought about the formation of the ancient Lake Bungunnia (Firman 1965). Tectonic movement was therefore the initiator of Blanchetown Clay deposition.

Flatland Geomorphology

Sturt (1849) began his account of exploration in Australia with this statement: "The Australian continent is not distinguished . . . by any prominent geographical feature . . . nor do any of its rivers . . ., not even the Murray, bear any proportion to the size of the continent itself". This description is particularly true with reference to the area now described.

Rivers

Meanders apart, the River Murray in the study area has a general direction of a little N. of W. To the W. of the Darling Anabranch this general direction is offset about 20 km by a section of the river that flows SW. The reason is not known, but it is suspected to be associated with tectonic influences that also caused the Darling Anabranch to gain entry to the Murray where it does. The locations of Wallpolla Creek with its anabranches and Boy Creek may be connected with this same pattern. The designers of the Chowilla Dam envisaged (at one stage at least) filling to the 205 ft. contour (62·5 m). This contour is based on the River Murray Survey of 1909-1914 when the South Australian datum was used, which is approximately 105 feet below Mean Sea Level. This unusual datum originates in the fact that part of South Australia (the Lake Eyre region) extends below sea-level. Thus the 205 ft. contour is approximately only 100 ft. (30·5 m) above M.S.L. although so far from the sea (Wentworth is about 820 km by river from the sea). This contour is relatively close to the river at the S.A. border but further E. swings out widely both N. and S. of the river. It nears the river again at the S. end of this SW. flowing sector, and follows it fairly closely to where this sector begins. The position is complex in the Wallpolla Creek area because this stream is actually an anastomosing system of used and abandoned channels, as though tectonically instigated shifts of channel had repeatedly occurred. Perhaps the curiously isolated, but large channel called Boy Creek is a former course of the Murray River. As our project had to cover so large an area in so brief total field work time, our investigation had to be of a reconnaissance nature, but in numerous places in this account interesting problems for future investigation (such as this one) will be indicated. Some are listed in Appendix 2.

The Darling River enters the Murray by twin streams—the Darling itself at Wentworth (Pl. 1) and the Darling Anabranch about 14·5 km further W. *Anabranch* is an Australian word and appears to have been used first by Colonel Jackson (1834, p. 79), who states "Thus such branches of a river as after separation re-unite, I would term anastomosing branches; or, if a word might be coined *anabranches*." Thereafter, it was used by Leichhardt (1847, 2: 35), Sturt (1849, 1: 93), Blandowski (1857, p. 174) and others. The word was spelt without the hyphen by Leichhardt, and I presume was originally used by Jackson only to indicate that he had taken the *ana* from *anastomosing* and joined it to *branch*. Sometimes the first syllable is spelt *anna* (first by Blandowski 1857, p. 128), which is incorrect by derivation, and sometimes as two words (as on the military map) which is not according to original usage.

The Darling and its Anabranch are both wide streams. Twin streams are like sympatric species of animals—one usually has a slight advantage over the other and in time takes over. However, both these streams flow strongly at present and a comparative study would be an interesting project. A string of lakes, filled only in flood time, is associated with the Darling in the Menindee district, while another group that could be regarded as belonging to the same system, is associated with the Anabranch. The origin of these lakes is unknown, but may have a similar genesis to that of Lake Victoria discussed later in this paper. Lake Menindee has yielded a rich deposit of fossil vertebrates (Tedford 1967), and more recently Lake Tandou further to the SW. has yielded a similar fauna, an account of which is provided in this *Memoir* by Dr. D. Merrilees. Further E., a similar system of dry lakes includes Lake Mungo, which has yielded records of both marsupial and human occupation plus evidence of high lake levels (Bowler et al. 1970).

The so-called creeks of the area are generally dry, and their significance is in the past rather than the present. The stratigraphy of the river flats at the Chowilla Dam site show a marked change in river regime. Six Mile Creek between the Darling and its Anabranch is an old river channel, as also probably is Boy Creek. All the creeks, and indeed the rivers themselves, are classifiable as misfit streams (Dury 1960). The amount of water that flows is small compared with distance traversed and the size of the valleys. It is important not to think in terms of the present flow, for the streams (especially the Murray) are controlled by dams and locks. Under natural conditions floods and droughts had severe effects. As recently as 1945 I walked dry shod across the bed of the Murray River near Koondrook. George Everard in an unpublished diary tells of a low river level in 1857 observed by him between Kulkyne and Wentworth. "We could cross quite easily in most places, having to swim the middle about a chain; the rest we could walk, the water being so shallow". Thus, under natural conditions the the river at times was not much of a barrier, whereas at present a high water level is always maintained.

The junction of the Murray and Darling Rivers (where the town of Wentworth stands) is an historic site, the area having been visited in:

1836 by Mitchell (1839, 2: 116)
1844 by Sturt (1849, 1: 103)
1853 by Mueller (Barnard 1904)
1856 by Blandowski (1857).

Rainfall and Floods

The rainfall is only 22-26 cm in this area, contributing little to river flow because it is so low, and because surficial sands soak up much of it. Some rain runs into enclosed areas which may result in salt lakes such as occur E. of the Lake Victoria dunes on Talgarry Station, and Salt Lake E. of the Wentworth-Renmark road on Dunedin Park Station. Heavy local falls may result from thunder storms. During our field work at Lake Victoria, one fall of 9 cm occurred, about 40 per cent of the average annual rainfall. The evaporation is about 1·8 m.

Flood water has two sources—Summer monsoonal water that flows down the Darling (Sturt 1849, 1 : 6), and Spring meltwater from the Kosciusko highlands further S. Normally, the floods do not coincide (as noted by Mitchell 1839, 2 : 116) but from time to time this happens, and king floods result. In the town of Wentworth a monument stands to the men and machines that saved the town during such a flood. The oscillation of flood and drought is a characteristic of this river system which has been present for a very long time, because the whole biotic complex is adapted to it. This characteristic ruined the boat trade, which was unable to depend on access. An extreme instance is that of the boat that went up the Darling to Bourke, but could not return for three years because a prolonged drought so lowered the water level that passage was impossible (Cameron 1966). In 1968 there was a flow in the Murray of 15,000 cusecs (35,000 1. per sec.) but in 1967 only 780 (1,800 1. per sec.) during a drought. However, in the major flood of 1956 the flow was 140,000 cusecs (330,000 1. per sec.). The largest recorded flood is 156,000 cusecs (368,000 1. per sec.). There was a Great Flood and rain in the Darling in 1863-4 (Hardy 1969, p. 134) that brought many hardships, but also green feed to an arid land. Such events could not be depended upon by settlers. For example, Tate (1885) records that floods filled Lake Momba in 1864 then not again until 1885. Cameron (1966) describes the big flood of the Darling River in 1890, and the unsuccessful attempts to save the town of Bourke.

Drought (Heathcote 1969) in Australia "is a permanent feature and not just a misadventure". It has to be planned for as a cyclic event. For some time this was not understood. For example in 1883 the Government was doubtful (Everard, n.d.) whether the N. part of Victoria, called The Mallee (Hardy 1914) "was worth saving". When Sturt reached the Darling River on Feb. 4th, 1829, at New Years Creek, he found the water too saline to be potable, and the Aboriginals had left the area.

River Terraces

Between Wentworth and the Chowilla Dam Site, the floor of the Murray River tract is exceptionally wide (Fig. 4). This is probably due to the river oscillating from side to side during the period of impedence while the stream was incising the Murray Gorge in the Pinnaroo Block. A local tectonic factor is also probably involved, as will be discussed in the section on the origin of Lake Victoria. It is the broadness of the river tract here that will cause so large an area to be inundated (1300 km^2) if a dam is built at Chowilla, and it is the usually steep walls of the valley tract that nevertheless will contain the water.

The river tract is an uneven pattern of dull gray and bright red. The gray alluvium is mostly, but not all, covered by the king floods, so some of it was deposited by still higher waters. However, the surface is relict (except for the lowest areas) and consists of old channels of well-washed sand and floodplains of clayey sand, which have not been masked by any later alluviation. These are comparable with the Coonambidgal Formation described by Butler (1958), Pels (1966), Bowler (1967), Firman (1967) and others. The gray country consists of uncompacted sediments that may be treacherous for the motorist in wet weather. The red country is compacted and passable in wet weather. The gray country is unoxidized, while the red is strongly oxidized. The gray country has little development of soil profiles, while the red has a well-developed soil profile with mobilization of carbonates in earthy patches to small nodules. The gray country is young, while the red country is much older.

Few fossils have been found in the gray country, but radiocarbon dates therefrom are Holocene. The red country has provided the mineralized bones of extinct marsupials, which elsewhere in this region are Pleistocene. The gray country is extremely flat and related to the baselevel of present deposition. Blandowski (1857, p. 127) was impressed with the flatness of this country describing "clay flats of remarkable evenness". In Brown's Paddock on Keera Station on the S. side of the Murray River, a survey from auger holes to a bench mark crossed about 0·3 km of gray floodplain and found only about 7 cm difference in level.

On the other hand, the red country consists of the remnants of a Pleistocene floodplain that stands well above (commonly 7 m) the existing floodplain (Fig. 5), and has suffered erosion, sometimes extensive. In the section on stratigraphy, this formation is described as the Rufus Formation, and some account of its sediments given. The Coonambidgal Formation is characterized by *Eucalyptus largiflorens* with *E. camaldulensis* along the waterways. The Rufus Formation is marked by non-myrtaceous plants such as Oldman Saltbush, *Atriplex nummularia, Callitris* and *Casuarina.* The great variety of the shapes of these outliers catches the eye on the air photos, but those checked proved to owe their morphology to the directions of the Coonambidgal channels. The small area covered by Rufus Formation outliers in Fig. 5 is a measure of the extensive erosion effected by the Coonambidgal streams. The strong contrast between the Coonambidgal Formation and the Rufus Formation in oxidation, compaction, pedology, erosion, secondary mineralisation and in palaeontology, indicates a considerable time break with consequent change of environment. It would be helpful to know how great this period is. No dependable chronology is yet available. There are indications of the order of age in that the lunette on the E. side of Lake Victoria onlaps the Rufus Formation there, which contains *Sarcophilus,* now extinct on the mainland. The oldest date from the Lake Victoria dune system so far is 17,530 yr (ANU-404A) but this is high in the succession so the base of the dune is considerably older. At Lake Mungo (Bowler et al. 1970), in this same river system, the base of the dune system is of the order of 32,000 years.

The deep weathering of the Rufus Formation would take a great deal of time. Norris (1969) says the process of reddening "is promoted by

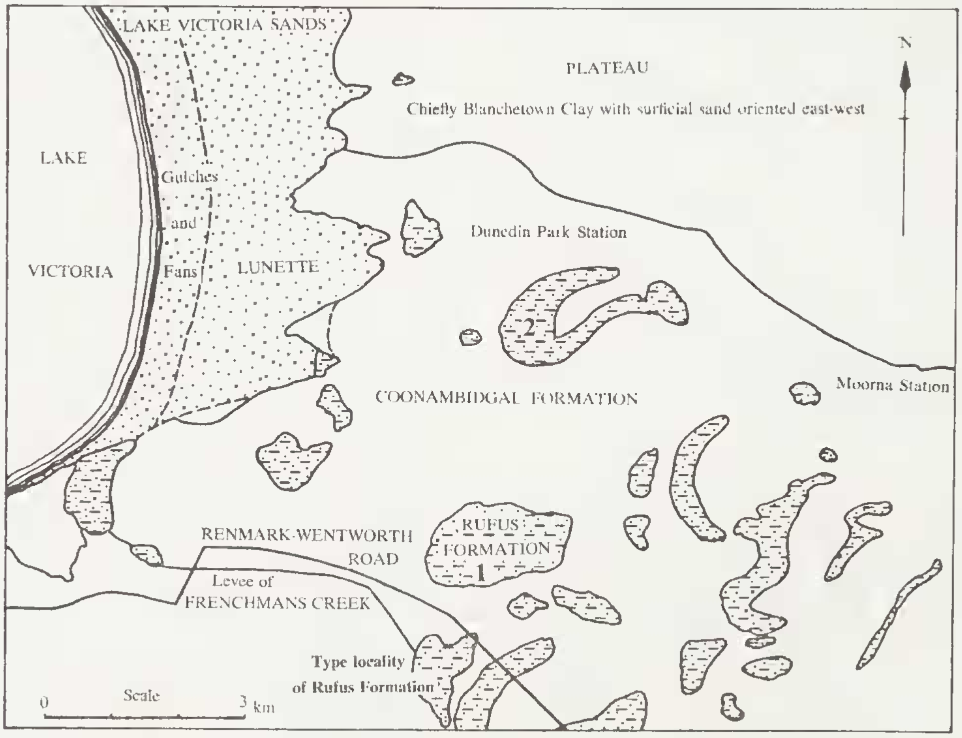


Fig. 5—Trace of air photos to show the distribution in the river valley (N. of the Murray River and E. of Lake Victoria) of the higher red country (Rufus Formation, oxidized remains of a Pleistocene fluviatile terrace) and the lower greenish gray country (Coonabidgal Formation). Sites 9-10.

warm temperatures, oxidizing conditions and the periodic presence of moisture. Reddening is due to the gradual weathering of iron oxide and silicate mineral grains; the weathering tends to cause the coatings to become thicker and affects increasing numbers with the passage of time. In addition, evidence suggests that the haematitic grain coatings are resistant to the abrasion associated with aeolian transport". Palaeoclimatic evidence indicates changes in river regime with time in the Murray valley, and it will probably be possible later to correlate this stratigraphic break between the Coonambidgal Formation and the Rufus Formation with one of those periods of change. The Rufus Formation may be middle Pleistocene in age.

Meanders and Oxbow Lakes

"All the varied forms of the land are dependent upon . . . structure, process and time". W. M. Davis 1954. In the area studied, the Murray River is a mass of meanders, and oxbow lakes (called billabongs in Australia) are very common (Pl. 3). This exceptionally extensive meander belt is worthy of closer study. In the short time available, the oxbow lake between Moorna Homestead and Woolshed close to the Wentworth-Renmark road (upstream from Fishermans Cliff and the paddock called The Selection) was studied briefly. This attractive body of water has a high biomass production. Some 60 species of birds were counted on or around it. On one occasion about 200 black swans alone were counted. Fish, tortoises, atypid prawns (determined by Dr. W. D. Williams) molluscs and ostracods were noted without a survey being made. Such places formed an important source of food for the Aborigines. This high biologic production results in carbonaceous sediments on the lake floor. When a drought was on, the lake level dropped and a spade hole was dug in the peaty floor at the S. end of the W. arm of the oxbow. It revealed only 23 cm of carbonaceous sediment over a highly compacted mottled clayey sand which is apparently the B horizon of a former soil.

The cliffs of the oxbow are very steep and the talus slope reaches only 0·2-0·5 of their height. Where gulches debouch into the billagong, there are small deltas covered with reeds. Thus the thickness of floor sediments and the morphology of the cliffs suggested a youthful age.

Figure 6 provides a surveyed section of the N. side of a gulch cut in the NW. cliff of the oxbow lake. This traverses the delta of sediment washed out of the gulch. The rainfall is only 23 cm p.a. but much of this often falls suddenly in thunderstorms and so erodes with high energy. Examination of other cliffs in the area showed this to be a widespread condition and hinted that there might have been a "1000 y. flood" or such event (or series of events) that cleaned out the river courses and oxbows by flooding of unusual energy. It was therefore decided to bore the floor of the oxbow lake to obtain sediment from the base of the "clay plug" for radiocarbon dating. If successful, this would give the order of age of the present geomorphic unit.

Mr. W. Levy kindly provided a boat. The Museum carpenters constructed a high tripod to stand on the floor of the lake to which a suitable boring apparatus could be attached. However, some 25 cm of very soft gray sediment made it difficult to set the tripod, the legs of which had to be heavily weighted to make them stable. C.S.I.R.O. Division of Applied Geomechanics, through its Chief, Dr. G. D. Aitchison, kindly supplied the boring apparatus and the services of Mr. Gavin Renfrey, without whose expertise we could not have mastered the many problems that arose. Ultimately, the core was taken, the profile being

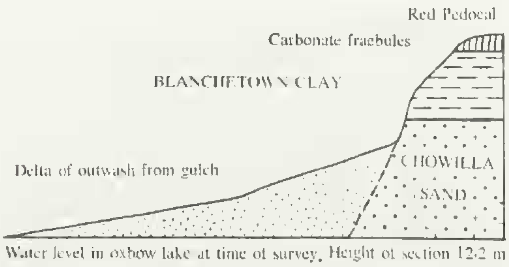


Fig. 6—Surveyed section, Moorna East oxbow, W. of Wentworth, N.S.W. Site 13.

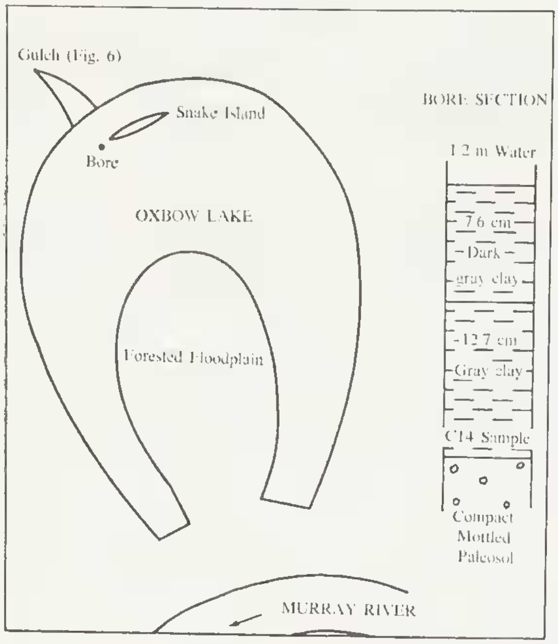


Fig. 7—Moorna East oxbow with the gulch beside which the section (Fig. 6) was surveyed; also site of bore. On right is section of bore. Radiocarbon date 770 ± 150 yr B.P. Site 13.

as in Fig. 7. The sample from the layer immediately above the eroded former land surface was dated by Professor K. Kigoshi as 770 ± 150 y. B. P. (GaK-3217). The carbon content was not as high as anticipated (the percentage fell off at the base) so that the sample was insufficient for a precise dating. However, the order of age was determined, and the juvenility of the oxbow lake established. This was all that could be done under the circumstances, but the further elucidation of this matter would be a worthwhile project.

Plain

The plain in which the river tract is incised is of the order of 36 m above the river (Pl. 2). The plain descends to the river or its floodplain usually by steep slopes or cliffs. From the air the green linear river tract contrasts strongly with the general redness of the terrain. To this natural ecology is now added the green patchwork of the irrigation blocks. A question worthy of investigation is why the Murray River has followed the course it has across this flat plain of lacustrine (Blanchetown Clay) and riverine sediments. As already pointed out, there are tectonic factors involved. There are also lithologic factors. It is noteworthy that a marked difference exists between the country S. of the river and that to the N. The Victorian section of the plain is characterized by the Big Desert and associated semi-arid sandy country, all geomorphically distinct by reason of its E-W. longitudinal dunes with sharply defined crests (air photos). These dunes have earthy carbonate subsoils, and calcrete nodules are only found (in my experience) under these dunes as quarries and borings showed. By contrast, the country N. of the river has relatively only a veneer of sand, and over large areas Blanchetown Clay outcrops at the surface. Thus, conservation of water S. of the river is a problem, while N. of the river large tanks excavated in the green Blanchetown Clay are common. As the air photos readily reveal, the country N. of the river has an E-W. grain with some development of longitudinal dunes, but the usual carbonate soils are those bearing laminated calcite nodules in the subsoil. As these two areas belong to different States, this important difference has not been indicated in studies published so far, and merits further investigation.

Because the Blanchetown Clay is of Upper Pliocene or Lower Pleistocene age, its surface is a relict landform. So also are the land surfaces consisting of Chowilla Sand, and further E. of prior streams (dating >40,000 by radiocarbon). Younger relict surfaces are dunes in the Mallee with uppermost subsoils dating 16,000-18,000 years (the substrate is of course older than the soil on it), and the sediments of the ancestral streams further E. that are not buried by later deposits.

Thus the broad flat plain of the Murray Basin is largely a relict surface of varying ages because

(a) The river system is confined to a tract cut into this plain, and
(b) The dune systems are mostly dead, or just being re-modelled.

The relict nature of the surface is also indicated by the polygenetic soils. The ground is packed with carbonates, which will be discussed (including their chronology) in a later section.

Relict surfaces imply terrain stability, but at the present time the countryside is characterized by instability. Gulches in active erosion characterize river banks and the sides of Lake Victoria. Much of the surface of the dune system on the E. side of Lake Victoria is now mobile with extensive blowouts and sandfalls. The fence between Nulla and Talgarry Stations on the E. side of Lake Victoria overlies three others because of the build-up of sand. Blowouts among the saltbush are common and a great number of such bushes have piles of loose sand under them. During the drought, dust storms were common. The reconciliation of relict terrains with all this instability is that the latter has mostly occurred since European occupation (as will be discussed later).

Finally, this review of planar areas above the floodplains should refer to some bordering flatlands or remnants of them along the river channels. At Cal Lal (Fig. 4) one descends from the general plain to a flat area well above the floodplain (e.g. behind the police station). This flat area (obviously once more extensive) is due to differential erosion, as the area corresponds with the top of a silicified zone that is part of a paleosol. The same kind of surface at the same stratigraphic level occurs on the E. bank of Salt Creek, Kulcurna Station, for some distance.

On the W. side of Lake Victoria there are mesas and promontories that suggest a former surface below the level of the general plain. It may represent a stage in the excavation of the Lake Victoria basin.

Salt Lakes and Swamps

When rain falls on the flat plain of this country, much of it lies about in claypans or penetrates dunes and sandspreads where it constitutes a temporary aquifer, apparently made use of by the Aboriginals. In other places the water runs into hollows with no outlets and salt lakes develop. Such depressions are not uncommon, but their origin has not been investigated.

Salt lakes have been noted in two types of geomorphic situation, viz.:

(a) In depressions, e.g. on Dunedin Park Station E. of the road from Wentworth to Nulla Station; also on Pine Camp Station.

(b) In negative areas where drainage has been cut off, such as behind the dune system at Lake Victoria. A salt lake occurs E. of the dunes on Talgarry Station S. of the track to the pump at Lake Victoria. To bore this lake, follow changes in regime, and by radiocarbon date its time of origin and history was a project that had to be abandoned for lack of time. As the dune system is apparently within the range of radiocarbon, presumably the lake is also, since it was formed by the dune system blocking the drainage.

Fletcher Lake NE. of Wentworth (Mildura military map, 2 cm=5 km) has a high lunette on the E. side. There are many dry lakes such as Lake Wallawalla (Fig. 4). Lake Cullulleraine is a water storage.

Cane grass swamps are common in the floodplain of the river system, a typical example being one on Moorna Station we called Triple Swamp by reason of its trilobed shape as seen in the air photos (Wentworth Run 2, 1363-5231, 9·7·65, NE. of C.P.) Stratigraphic sections from the cliff behind this swamp are described later.

In the NE. part of Lake Victoria basin behind the dune system E. of the lake is a cane grass swamp. An auger hole was sunk about 20 m E. of the track that passes it, and traversed on 24th July, 1969:

0·0 –0·3 m	Reddish brown (Munsell 2·5 YR 5/4) clayey sand gradually merging to
0·3 –0·63m	Light brown (7·5 YR 6/4) sand with hard carbonate
0·63–2·13m	Light yellowish brown (10 YR 6/4) slightly clayey sand without carbonate. Moisture at 2m and so a little darker
2·13–2·59m	Mottles of light gray (5 YR 7/1). Becomes greenish gray (5BG 7/1) at 2·31m. Pyrolusite at 2·53m. Heavy at 2·61m.
2·59–3·07m	Very pale brown (10 YR 7/3) sand. Darker material included 2·74–3·04m.
3·07m +	Light gray mottles again. Salty water at 3·35m.

Claypans (small playas)

This term is widely used in Australia but, although related in meaning to "playa" (Chico 1968), is not its equivalent. The term playa is used in many senses, but in Australia is applied to a large dry lake (Jutson 1934), while "salina" or "salt lake" (e.g. Bettenay 1962) is employed if a salt crust is present. A claypan is a small flat unvegetated area, in an arid or semi-arid environment characterized by sheetflood deposition of fine sediments (usually red to pale brown). In the area studied claypans are commonly 20 to 30 m in diameter and tend to be round in shape. On Nulla Station some large claypans were joined up to form an air strip for light planes in fine weather.

By extension, the term claypan is used also in the study area for places of similar appearance to the above, which are in reality places stripped by wind erosion of the surficial sand to expose a flat hardpan of similar sand bound by clay skins. Such sediments do not effervesce on application of acid, and so the amount of carbonate is negligible. On such stripped zones Aboriginal implements and rock debris form a lag deposit; also lumps of baked clay that were used as cooking stones (to be discussed later). Claypans can form in dunelands by centripetal wash of the fine fraction which has either been blown up into the dunes as aggregates or deposited on them by aerial transport. Fossil claypans of this type occur in the dune system on the E. side of Lake Victoria. They are characterized by fine herringbone rills when exposed.

Two important features of the geomorphology remain for comment, but each is a major topic and so individual sections will be devoted to them, viz.:

(a) Dunes
(b) Lake Victoria.

Dunes

The semi-arid Murray Basin, with its extensive fluviatile sand sources and a wind regime with seasonal persistent westerlies (Fig. 8), is a natural setting for dunefields.

The Murray River at Echuca adopts a NW. trend which it maintains overall as far as S.

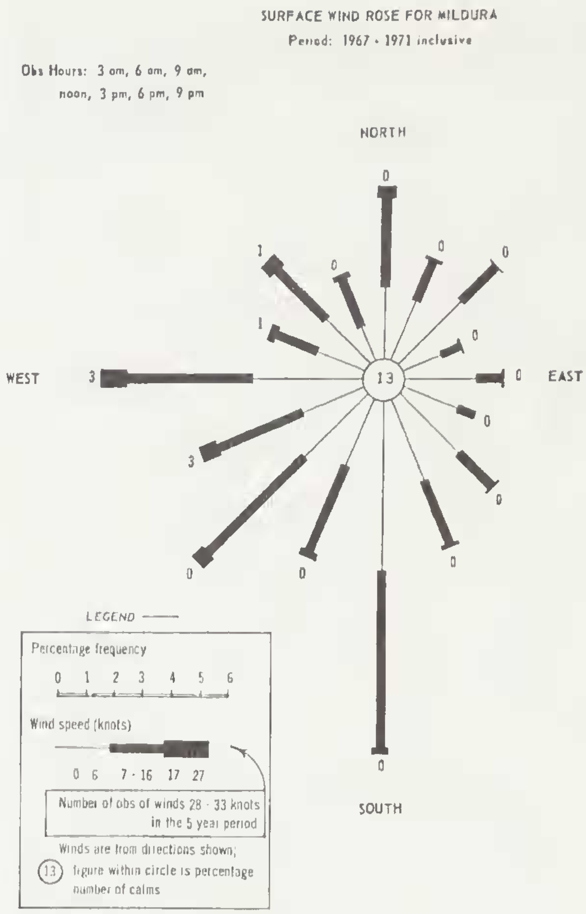


Fig. 8—Wind rose showing the predominant W. winds that determine the direction of the longitudinal dunes. Prepared by The Commonwealth Bureau of Meteorology.

Australia. This is also the orientation of the broad ridges that constitute the chief geomorphic feature of the Mallee in N. Victoria (Hills 1939, Thomas 1952, Lawrence 1966). Lakes and other surface features (and as a result the railways) are affected by this general trend, but it has no relation to the configuration of the bedrock below the Murray Basin sediments. Across this lineation are the E-W. longitudinal dunes of the surficial Woorinen Formation (Lawrence 1966, Fig. 8). In some places the dunes spill into lakes, proving their longitudinal character and direction of sand movement.

Following the Murray river to the NW. from Echuca is a large very flat floodplain (of both present and past) consisting of very clayey sediments and without ridges. NW. of Benjeroop the flat plain ceases, and areas of red soil with hard carbonate nodules rise like islands above the gray sediments (e.g. near "Winlaton" homestead). It may be that the Leaghur Fault of Macumber (1969) at its north end swings round the N. margin of the Gredgwin Ridge to this area, and is partly responsible for this change in terrain.

The broad NW.-SE. Mallee ridges represent the interfluves of rivers once active, while the E-W. longitudinal dunes represent the drying up of the rivers and establishment of a desert. Thus Mabbutt (1968) remarks about Central Australia deserts—"As in most of the world's deserts, aeolian sand surfaces mark the retraction and disintegration of drainage systems and the abandonment to wind action of coarse-textured alluvia in former depositional environments".

The evidence of former rivers signifies more humid conditions (at least in the areas of origin), while the establishment of the dunes proves drier conditions. That the dune system is now inactive except for some of the more sandy crests, that they are almost completely vegetated, and that they commonly have a fairly deep soil developed on their surfaces, proves that conditions are less desertic than when the dunes were formed, i.e. the climate has been both more humid (rivers) and drier (desert) respectively.

The dunes are parallel, which is "characteristic of large open expanses of dunes where sand movement has been least complicated by relief or drainage" (Mabbutt 1968). The climax of dune building was when this system was active. Mabbutt and Sullivan (1968) discuss whether the dunes of the Simpson Desert are normal dunes or windrifts (swales formed by corrasion). They support the former view but perhaps these ideas should not be set in apposition, as at least some of the dunes in the Simpson Desert have cores of older material, as do some in the Mallee. As subsequent evidence will indicate, the Mallee ridges are polycyclic as observed by Hills (1939). Jennings (1968) notes that desert dunes cover 19 per cent of Australia. His map shows an Australia-wide response in dune trend to the continent's overall wind system. The directions of the dunes in our study fit the continental pattern of wind directions. It is likely that during the Last Glacial at certain times the Mallee with its active dunes was comparable to the present Simpson Desert. For more information on the Simpson Desert see Folk (1969, 1971) and Boyland (1971). Thus there has been a range of regimes from river country to dust bowl.

Like the savanna lands of other parts of the world, those in Australia reflect the climatic variations of past ages. They are marginal areas that more readily register climatic shifts. Thus Thomas (1971) says, "Thick duricrusts beside the River Niger near Niamey were formed under humid conditions in the Tertiary period: sand dunes are about 20,000 years old but are fixed". "Chad Basin in W. Africa provides evidence of former climates. During arid phase over 20,000 years ago, seif dunes trending NE. to SW. were formed. By 10,000 years ago wetter conditions had fed enlarged 'Mega-Chad' . . . . In the last 7,000 years the climate has come drier and Lake Chad has shrunk. Transverse dunes appeared during minor climatic changes".

Mallee Dunefield

Hills *et al.* (1966) state that "Longitudinal dunes are best developed where there is an abundant supply of sand, especially in large alluvial basins". The Mallee Dunefield of E-W. longitudinal dunes is a re-organisation of sand from the Diapur Sand, Chowilla Sand and such, during dry periods. The dunes exist because there was an adequate supply of sand to windward, and the aeolian traction was sufficient to move the sand, but not strong enough to cause only deflation (as on a gibber plain), leaving a lag deposit. The climate of the time was dry enough for the sand to be mobile, and for the vegetation to be depressed enough to prevent immobilization of the dunes. The dunefield is extensive even more so than is shown on the World Aeronautical Chart, or on the map in the Reader's Digest Complete Atlas of

Australia (1968). On the aerial photos, the dunes are very distinct and the crests appear sharp, but on the ground they appear rounded. This is of course a matter of scale. As the field has long been immobile, the crests cannot remain sharp as in an active dune system. The first two years of our observations were a time of drought, and this field was also observed by the writer during the severe 1945 drought. During the latter, the country was denuded of green herbage, and even the domestic geese flew round of an evening (usually they are too heavy). However, the dunefield was not reactivated. The crests in more sandy areas became mobile but the system as such remained inactive. The dunefield is thus definitely relict. However, we should think in terms of the natural conditions that existed in the Mallee before European occupation, because the latter has greatly increased sand movement. The western Mallee is less stable than the eastern part. Some idea of the Mallee in its original state can be obtained from early observers as recorded, for example, by Blandowski (1857), Bride (1898), Everard (n.d.), Hardy (1969), Hawdon (1852), Kenyon (1942), and Morton (1861).

1. *Swan Hill Paleosols*

Churchward (1961, 1963 a-c) studied these dunes and their soils in the Swan Hill area on the Murray River. As a pedologist he was concerned chiefly with the soil mantles, and his findings can be summarised thus:

It is to be noted that with increasing age the soils are more mature, therefore one would expect each pedogenic phase to be successively longer. The increasing maturity of the soils is shown by the depth of carbonate leaching, the degree of clay segregation, the pedality, the amount of development of lustre on the ped faces and compaction status. Each of these factors involves time. However, the length of time between the dates for the Speewa and Kyalite soils is not less than that between the dates for the Byamue and Speewa soils, but 47 per cent more. No simple damped harmonic curve can therefore express the history on present evidence. The reason is that two unrelated factors are involved, viz. the accumulation of the substrate (dune building), and the modification of the substrate surface by pedogenic processes (soil formation). The former is an unstable phase of the terrain, and the latter a stable phase. Oscillation of these states is indicated by the successive dune deposits and soils. However, the diminishing intensity of soil formation raises the question as to whether widespread palaeoclimatic changes are involved or local variations. This can be checked by examining what has happened in other parts of of the dunefield. During the present Project, such checks were made. Multiple paleosols were found to characterize the dunefield. Two paleosols were the commonest, but three and sometimes four were also found. Sections at three widely spaced localities are given in the following paragraphs with radiocarbon datings of the soil carbonates. The reliability of such dates will be discussed in the section on palaeopedology, and the climatic phases in the section on palaeoclimatology.

SOIL MANTLE	LIME	CLAY	PEDALITY	PED FACES	COMPACTION
4. *KYALITE* (15,550 yr)	No mobilisation	No segregation	None	None	Soft granular structure with organic buildup
3. *SPEEWA* (24,000 yr)	At 35cm	Movement A to B	Weak	Low lustre clay skins	Firm
2. *BYAMUE* (29,750 yr)	At 120cm	Strong segregation	High	Thick glossy clay skins	Dense
1. *TOOLYBUCK* (Oldest)	None—becoming acid	Very strong segregation	Very high	Very glossy clay skins	Very dense

The dates provided have been published by the Australian National University in *Radiocarbon* vol. 12, and the laboratory numbers from youngest to oldest are ANU-183, 184, 185 respectively.

2. *Ouyen Paleosols*

In 1939 Hills drew attention to evidence of this kind in the same dunefield N. of Ouyen at and near the 290 mile post. Carbonate layers on the Calder Highway (p. 315, Pl. 24, fig. 2) he interpreted correctly as paleosols and indicators of more humid periods during the time of dune building. On the same highway 1 km S. of the 283 milepost (about 3·2 km N. of Ouyen and 4·8 km S. of Kiamal), there is a site on the W. side of the highway about 90 m S. of a branch road on the E. side where I studied the roadcut shown in Figure 9. The section comprised:

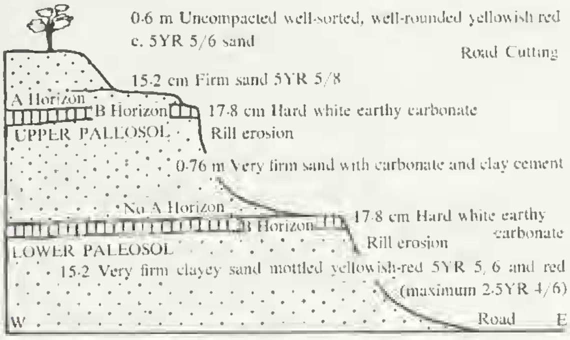


Fig. 9—Roadcut about 3·2 km N. of Ouyen, N. Victoria, on the Calder Highway, showing carbonate paleosols in E-W. dune (Woorinen Formation). Carbonate from the upper paleosol dated c. 16,400 yr B.P.

60cm	Uncompacted well-sorted well-rounded aeolian sand of variable colour but around yellowish-red 5 YR 5/6.
15cm	Yellowish-red 5 YR 5/8 firm sand
c.18cm	Hard white carbonate of earthy type (not solid crystalline) of variable thickness along the outcrop, grading into
69cm	Very firm clayey sand with some carbonate and clay cement, characterized by rill erosion.
c·15cm	White carbonate similar to the horizon above
90cm	Very firm clayey sand, mottled yellowish-red (5 YR 5/6) and red (to maximal 2·5 YR 4/6) with rill erosion.

The two carbonate layers are B horizons. The clay in the dune sands is interpreted as windblown dust washed in by rainwater (cf. Gill 1966, p. 556). Even at the present time much fine red dust is blown over the Dividing Range to S. Victoria (Chapman and Grayson 1903) and E. to the Snowy Mts. and beyond (Walker and Costin 1971).

From the upper carbonate layer a sample was collected, which yielded a radiocarbon date of $16{,}400 {+450 \atop -560}$ yr B. P. (GaK-3218). This is comparable in age with the date of 15,550 yr at Swan Hill for the Kyalite soil. As soils take a good deal of time to develop, and are not perfectly synchronous over their range, such variations in age are to be expected. See also the discussion of carbonate dates in the section on palaeopedology.

3. *Hattah Paleosols*

On the E. side of the Calder Highway (79) between mileposts 309 and 310 (from Melbourne) there are extensive pits for the removal of carbonate soil nodules for road works. On the S. side of the entrance track, a roadcut sections an E-W. dune. As pits with nodules occur to the E. of the cutting on the axis of the dune, and no nodules are found in the dunes, it was surmised that the nodule bed underlies the dunes. To test this an auger hole was put down on the N. slope of the dune near the road and overlooking the access track. The section proved was:

20cm	Reddish yellow 5 YR 6/6 fine sand merging to
18cm	Light red 2·5 YR 6/6 fine sand merging to
63cm	Light red 2·5 YR 6/6 fine sand merging to
43cm	Fine sand with earthy carbonate as small firm lumps up to 0·6cm diameter. Colour lighter because of carbonate, on decrease of which 6/6 then 6/4 (light reddish brown) grading to
51cm	Reddish-yellow 5 YR 7/6 fine sand still with some carbonate. Slightly lighter at 170cm from surface. Carbonate disappeared at 196cm from surface. Merging over 13cm to
53cm	Reddish-yellow 5 YR 7/8 fine sand
13cm	Reddish yellow 7·5 YR 7/6 more clayey fine sand (colour and texture change, merging to
28cm	Pink 7·5 YR 7/4 fine sand with solid carbonate nodules which stopped the auger at 290cm.

This section is interpreted as follows:

Soil 1	0–1·01m	A horizon
	1·01–1·95m	B horizon with carbonate
Substrate	1·95–2·48m	Dune sand
Disconformity		
Soil 2	2·48–2·61 m	Remainder of A horizon of original terrain or top of B horizon.
	2·61–2·90+m	B horizon of original terrain.

Nodules from the lowest part of the above auger hole (site approximately 142° 15′E, 34° 46′S) were radiocarbon dated by Dr. T. A.

Rafter, New Zealand Institute of Nuclear Sciences (Lab. no. R 2729/4) with the result of 27,500 ± 70 yr B.P. $\delta^{13}C$ w. r. t. PDB = —3·5‰. This is comparable with a dating of 27,800 obtained for similar material from N. of the River Murray (to be discussed later).

If my interpretation of the above section be correct, then this date is the maximal age for commencement of dune building at this site. Indeed, it is probably quite in excess of that time, because the date is an average of the many years required to grow such a nodule. For the purpose of this argument the C14 date is taken at its face value.

4. *Berribee Station Paleosols*

Berribee Station is situated in the far NW. corner of Victoria on the S. side of the Murray River. Two types of dunes occur there, viz. the E-W. longitudinal dunes of the Mallee Dunefield, and channel-bordering dunes of the Coonambidgal complex on anabranches of the Murray River. In the air photo constituting Plate 4, three oblique zones of different types of country can be readily discerned, viz.:

a. *Coonambidgal Country,* consisting of the present Murray River channel to the N., the anastomosing Lindsay River to the S., other anabranches and past channels, all with their respective floodplains.

b. *E-W. Dune Country* occupying the S-W. sector of the photo. Zones 1 and 2 meet in the NW. sector of the photo, where they are separated by a cliff.

c. *Relict Floodplain.* This intermediate zone in the middle and SE. sectors of the photo is above present river floodings but has apparently been subject to inundation in the past. One use is for crops (as can be seen in the photo) and is partly irrigated. From the photo it can be seen that the E-W. dunes penetrate it. This is obvious on the ground, as when the auger was sunk, it was considered to be in the zone of the dunes. It is thus an area of interdigitation of the dune-building and riverine processes. The site is marked on the air photo in Pl. 4, and is approximately 142°4′ E and 34°8′. It is about 2·6 km SSW. of the Berribee homestead (Mildura military map c. 408,785). The site is on the summit of an E-W. dune, and the auger penetrated:

38 cm	Red sand 10 R 4/6 (moist)
190 cm	Light red sand 2·5 YR 6/6 with earthy carbonate fraebules up to 1·3cm diameter but generally smaller. Most can be broken in the fingers. From 203-365cm from the surface there is a greater concentration of carbonates with fraebules up to 2·5cm in diameter. Carbonate zone 1.
36 cm	Red sand 2·5 YR 5/8. No carbonate present, hard lumps being due to cementation by clay, pyrolusite and such.
53 cm	Red sand 2·5 YR 5/6 with earthy carbonate sometimes forming fraebules that can be broken by the fingers. Carbonate zone 2.
132 cm	Red sand 2·5 YR 5/8 without carbonate. Lumpy as 36cm band above.
104 cm	Gray 5 YR 6/1 fine sandy clay with white earthy carbonate and pyrolusite. Carbonate zone 3.
13+cm	Same matrix without carbonate.

This section is shown diagrammatically in Fig. 10 to visually communicate that more than half the profile is full of earthy carbonate. My interpretation of this section is:

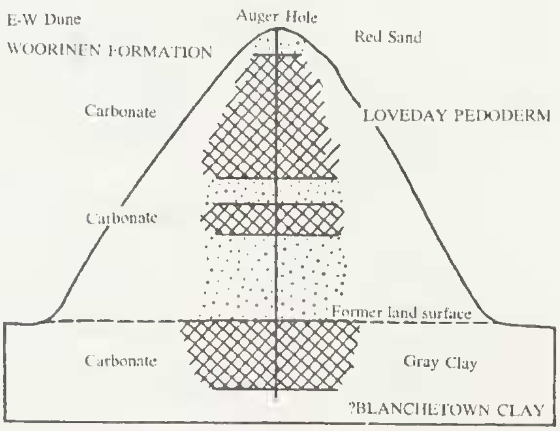


Fig. 10—Section of E-W dune c. 2·6 km SW of Berribee Station homestead, S. of the River Road, NW. Victoria (Pl. 4). Site 19.

Soil 1	0·0–0·38 m	A horizon of pedocal
	0·38–2·28 m	B horizon
Soil 2	2·28–2·64 m	A horizon
	2·64–3·17 m	B horizon
Dune Sand	3·17–4·49 m	
Disconformity at base of dune		
Soil 3	4·49–5·53 m	B horizon of truncated soil profile on Pleistocene alluvial terrace
Alluvium	5·53–5·66+m	Flood plain sediments.

Other interpretations are possible. The saturation of this section with carbonate requires explanation. There appears to be far too much to be derived from the sediments themselves. Not far away in S. Australia marine limestone and later carbonate rocks are exposed, which could have been a source of windblown carbonate dust that was transported by W. winds to the site. (cf. Chapman and Grayson 1903, Walker and Costin 1971, Glasby 1971).

Dr. T. A. Rafter also assayed these carbonates for radiocarbon content and calculated the following C14 ages:

Carbonate zone 1 14,200 ± 790 yr B.P.
$\delta^{13}C$ w.r.t. PDB = $3{\cdot}5^0/_{00}$
Carbonate zone 2 31,300 ± 1,200 yr. B.P.
$\delta^{13}C$ w.r.t. PDB = $-2{\cdot}1^0/_{00}$
Carbonate zone 3 Beyond C14 range
$1\sigma >$ 34,300 B.P.
$2\sigma >$ 28,800 B.P.
$\delta^{13}C$ w.r.t. PDB = $-3{\cdot}5^0/_{00}$

For logs of two other auger holes in this vicinity see section on sedimentology.

All the datings of the E-W. dunes are on carbonate of the same type, and deposited under the same conditions. Indeed much of it may have the same origin, blown in on the prevailing W. winds that built the dunes. It is reasonable therefore to directly compare these dates. Considering the variables in pedogenesis, the dates match well. They indicate at least three periods of terrain stability when soils formed:

3 $\sim$ 16,000 yr. B.P.
2 $\sim$ 28,000 yr. B.P.
1 > C14

After each phase of dune-building, the morphology was depressed by weathering and erosion, as is indicated by the near horizontal soils.

The dunes of the Mallee Dunefield belong to the Woorinen Formation, which will be discussed in the section on stratigraphy. Some grain size analyses of the sediments will also be reported later in the paper.

5. *Lowan Sands*

It has been mentioned that there is more surficial instability of the terrain in the W. of the Mallee Dunefield than in the E. This is due to the tongues of Lowan Sands (Lawrence 1966, Fig. 8) that cross the area like giant blowouts. The origin of these sands has been discussed by Hills (1939), Crocker (1946) and Lawrence (1966). Because of the low dynamics of the Murray River system the Parilla Sand, Chowilla Sand, Diapur Sandstone and other sand formations are all characterized by unusually fine grades that make them rather similar. It is therefore not easy to specify the formations that have provided the quartz sand for these dunes. These sands are polycyclic. The sand forming the dunes on the E. side of Lake Victoria was carried on site by river action, and bears the general character of the sands of this sedimentary basin. They are thus not typical dune sands, but finer than usual. Because polycyclic, they are well rounded and well sorted, thus contrasting with the dunes of the Simpson Desert (Folk 1971, p. 47) "but briefly removed from their poorly-sorted fluvial source material".

6. *Lindsay Island Dunes*

This island is the area between the Murray River and the anastomosing Lindsay River (an anabranch). It consists of Coonambidgal sediments, and comprises mainly the following types of deposit:

a. Greenish-gray to gray clayey sand flood plain deposit (red gum flats).
b. Well washed light brownish gray channel sands.
c. Channel-border dunes (with Murray pines) developed by aeolian action on the channel sands.

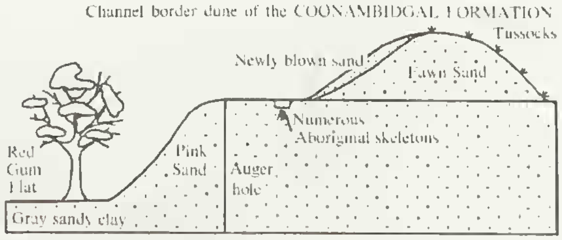


Fig. 11—Surveyed section of channel border dune oriented N-S. on Lindsay Island. Berribee Station, NW. Victoria.

The air photo constituting Plate 4 shows part of this area, and in particular the two-mile long N-S channel bordering dune which is part of site 19. Figure 11 is a section across this dune, and the logs of the auger holes there shown are as follow:

Auger 1 99cm Light brown 7·5 YR 6/4 to light yellowish brown 10 YR 6/4 silica sand merging to
38cm Pale brown 10 YR 6/3 sand merging to
137cm Light yellowish brown 10 YR 6/5 sand
282cm Pale brown 10 YR 6/3 sand
15cm Compact mottled light gray 10 YR 7/1 and reddish-yellow 7·5 YR 6/6 clayey silt.

This profile is interpreted as:

0–5·56 m Dune sand with little variation (oxidized).
5·56–5·71⁺m Riverine Coonambidgal sediments (reduced).

Auger 2 10cm Dusky red sand 2·5 YR 3/2 moist, merging to
28cm Reddish brown 5 YR 4/4 sand merging to
53cm Reddish yellow 7·5 YR 6/6 sand merging to
41cm Yellowish red 5 YR 5/6 sand merging to
79cm Light yellowish brown 10 YR 6/4 sand merging to
107cm Very pale brown 10 YR 7/3 sand
58cm Mottled clayey fine sand—light gray near 5 YR 7/1 and reddish yellow 7·5 YR 6/6. Occasional streaks are a stronger red. At 3·07m carbon present and iron oxide straight narrow markings that appear to be root sites.
137cm Similar sediments with changing percentage of fines and changing amount of mottling.

This profile is interpreted as:

0–3·71m Oxidized aeolian sand with a thin juvenile soil.
3·71–5·36m Gleyed riverine Coonambidgal sediments

Auger 3 10cm Pinkish gray 7·5 YR 6/2 well sorted and well-washed sand.
36cm Light gray 10 YR 7/1 poorly sorted sand including grades heavier than in dunes
33cm Lighter gray N 7 sand, poorly sorted and with clay balls. Auger brought up half of one 3·8cm in diameter plus other pieces. Merging to
8cm Light brownish gray 2·5 YR 6/2 sand with a few streaks of light olive brown 2·5 YR 5/4.
28cm Offwhite (near N8) sand

The final 36 cm of the hole were difficult to drill as the sand was running so freely. The log is interpreted thus:

0– 10cm Dune slope wash
10–175cm Oxidized, mostly well-washed riverine sands less sorted than dune sand derived from them.

Grain size analyses have been carried out on some samples, and are reported later in this paper.

Cal Lal Dunefield

In the study area a distinct difference exists between the country N. of the Murray River and that S. of it, so that the course of the Murray may be a function of this difference, modified by the minor tectonics already described. The Mallee Dunefield to the S. is a complex of E-W. longitudinal dunes with pedocals of earthy carbonate. It is a sandy terrain. The area N. of the river is characterized by a substrate of impermeable green Blanchetown Clay with a complex pedocal containing solid crystalline calcite nodules. At first the terrain appears to be a typical sandy one, but closer examination shows that the sand is largely a veneer. The excavations for water "tanks" show this well, as also did our spade and auger holes. The air photos show that some areas N. of the river have well-developed dunes, and some have none, but overall an E-W. grain is present, developed undoubtedly by the persistent W. winds. Dunes N. of the river are best developed in the study area close to

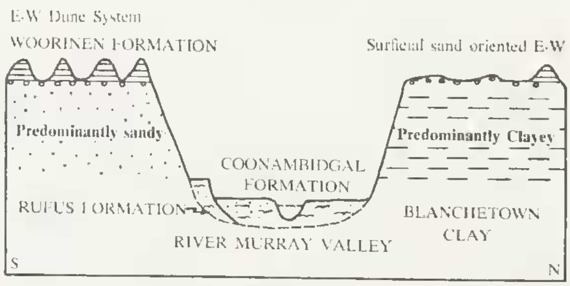


Fig. 12—Notional section of Mallee and Lake Victoria dunefields to show their different character due to different substrates. The river follows the interface. Thus farmers in the Mallee have difficulty retaining irrigation water, while N. of the river water tanks are dug directly into the surface.

Fig. 13—Map of Lake Victoria and environs showing features pertinent to this study. Based on Engineering and Water Supply Chowilla Dam map (S. Australian Government).

sources of sand e.g. E. of Lake Victoria. The difference between the country N. and S. of the river is fundamentally that the S. country has a sandy substrate (Diapur sandstone, Chowilla Sand and such) while the N. country has a clayey substrate.

It is to be expected that the river would find and follow the interface between the two (Fig. 12). In the short time available for this Project the idea could not be developed, but its clarification seems important for understanding the country and for the planning of irrigation, water conservation, groundwater utilization and such like.

Mt. Hancock Dune

Any eminence in a flat terrain appears important. From considerable distances one can see a large dune of mobile sand that has been given the name of Mt. Hancock. It surmounts the high cliffs on the E. side of Salt Creek near its confluence with the Murray River, and is approximately N. of Kulcurna Homestead. The structure is conspicuous because so elevated, isolated, and of light colour due to absence of vegetation. Its origin is a function of lateral differentiation and placement relative to prevailing winds. At this cliff site, the Blanchetown Clay cuts out, and the Chowilla Sand takes over a great part of the cliff section, as can be seen also on the right bank of the Murray River between Kulcurna Homestead and Salt Creek. As the Chowilla Sand is a well-washed sand, it breaks down to loose sand very readily except where it is affected by the paleosol that mobilised silica. The cliff below Mt. Hancock has thus a good supply of free sand, an adequate source of material for dune building. As the cliff is on the E. bank of Salt Creek, the prevailing W. winds supply the necessary traction. As W. of the creek is a very extensive lowland flood plain, the winds are able to exercise their full force.

Lake Victoria

"Beneath me lay a beautiful lake, about 30 or 40 miles in circumference, with a line of gum trees scattered along its edge . . . To this splendid lake of which I had the pleasure of being the first European discoverer I gave the name of Lake Victoria" (Hawdon 1852, pp. 42-3). Hawdon made his journey in 1838 and named the lake after Queen Victoria.

Shortly afterwards Sturt (1849, vol. 1: 94) gave this description—"Lake Victoria is a very pretty sheet of water, 24 miles in diameter, very shallow, and at times nearly dry. It is connected with the Murray by the Rufus, and by this distribution of its waters the floods of the Murray are prevented from being excessive".

It should be noted that there was some early confusion in nomenclature. For example Bonwick (1855) refers to Lake Victoria but his maps show two lakes of this name, viz. (1). What is now called Lake Alexandrina at the seaward terminus of the Murray River, and (2) Lake Victoria, between the River Darling and the S. Australian border.

"Among the unlicensed Murray squatters were Edward Meade Bagot . . . and George Melrose who came up the river in 1847 to occupy the bush frontages of Lake Victoria. The latter's shepherded flocks did so well that he would have liked to legalize his claim but this was impossible. Until the position of the border was fixed, he discovered, neither colony was in a position to grant a lease. The charms of Lake Victoria so attracted Melrose that he chose it to honeymoon with his Scottish bride, Euphemia—as the first white man's lubra to be seen in those parts she caused quite a stir amongst the Aboriginal tribes" (Hardy 1969, p 63). Melrose, tired of waiting for a lease, went elsewhere. The surveys were not completed until 1854. However, we have here a picture of a beautiful lake with vegetated banks when first visited.

The foregoing descriptions will again be relevant when present day erosion patterns are discussed.

Lake Victoria (Figs. 4, 13) is 13 km long and 10 km wide with an axis oriented a little W. of N. Under natural conditions only the S. end was full, a heavy flood being needed to cover the whole present lake bed. In the early days of settlement the Wentworth to Renmark road or track crossed the N. end of the lake bed as also did the telephone line. Lake Victoria

(Pl. 5) is now a reservoir. Waters held in the Menindee Lakes on the Darling River can be released down that stream and by control at Lock 8 diverted through Frenchmans Creek (bordered by artificial levees) into Lake Victoria. They are released through a regulator down the Rufus River and so into the Murray River again. Although 732 km by river from the sea, Lock 8 is only 25 m above sealevel.

Distinct from the existing Lake Victoria is the basin of which the present lake occupies only a part. This basin is sunk into the plateau of Blanchetown Clay and associated formations so that the level of the reservoir is 30-35 m below plateau level. The water is about 16 m maximum depth and an unknown depth of sediments lies below that, but these are shallow judging by the mode of genesis of the lake. The basin thus probably reaches a maximum of the order of 38 m below the general plateau level. (The present lake is pressed against the W. perimeter of the basin, which is scalloped by a series of erosion amphitheatres (Fig. 14) that are separated by promontories somewhat lower than the plateau level. On the E. shore of the lake is a large lunette, about 14 km long and up to 2·4 km wide. To the NE. of the lake is a large area approaching half the size of the lake consisting of lunette backed by swamps, claypans and relics of Rufus Formation. Separated by a promontory from this NE. area is one to the SE. which is of different character again, consisting of ancient Coonambidgal floodplain and channel sediments through which stand outliers of Rufus Formation. This area stretches SE. to Moorna Station and S. to Frenchmans Creek. Thus in the Lake Victoria basin there are four geomorphic elements:

1. The erosion amphitheatres on the W. perimeter.
2. The lake.
3. The NE. area with lunette, swamps, claypans and Rufus Formation outliers.
4. The SE. area composed of greenish grey Coonambidgal Formation sediments with higher red relics of Rufus Formation.

On a map the lake is seen to be a smooth-shored oval stretch of water but the basin in which it lies has no such character. The basin is about twice the area of the lake, but in view of its shape, it is not easy to decide where its S. boundary should be. The perimeter of the basin is irregular on the W. because scalloped, and in the E. has broad rounded sweeps. Any explanation of the genesis of the lake must account for these features.

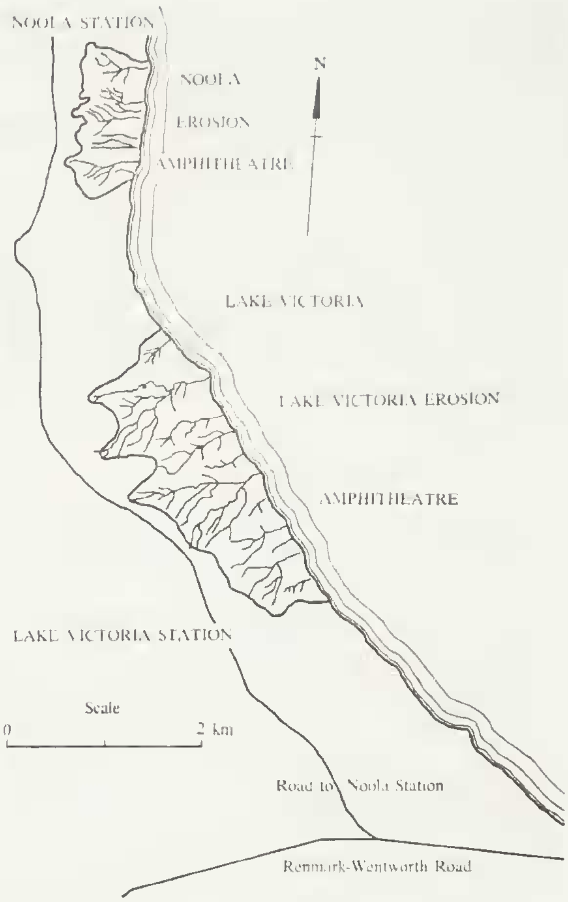


Fig. 14—Erosion amphitheatres on the W. shore of Lake Victoria, N.S.W. Based on air photos. Site 6.

Genesis of Lake Victoria

If the Lake Victoria basin is considered apart from the present lake and lunette, it is seen to be an area wide open to the S. It is not enclosed with a narrow outlet as is the present lake due to the encircling W. perimeter of the basin on one side and the lunette on the other. The axis of the basin is similar to that of the lake, i.e. deflected to the W. As the Blanchetown Clay and associated formations continue round the walls of the basin without appreciable change, the basin does not owe its presence to faulting. It is erosional, scoured by the ancestral Murray (or a large anabranch, or both) deflected NW. from the present course. It would appear that the stream left the present valley tract in the general area of Moorna Station homestead (Parish of Moorna) and ran more or less NW. through the Parishes of Utah and Wangumma to the Lake Victoria region. The Lake Victoria basin is thus regarded as a giant billabong and the scalloped margins are probably remnants of the Pleistocene meanders there. The time of formation was after the deposition of the Blanchetown Clay (Plio-Pleistocene) because, with associated deposits it forms the plateau. On the other hand, the basin was cut before the deposition of the red Rufus Formation because relics of this terrace occur in the main Murray River tract, in the open S. end of the basin (Dunedin Park Station) and in the more restricted NW. area of the basin behind the lunette. After the Rufus Formation was formed, some change in the river regime resulted in cessation of terrace-building, deeper scouring of the river tract, and then deposition of the Monoman and Coonambidgal Formations. This explanation of the Lake Victoria basin accounts for its stratigraphy and geomorphology. It also accounts for its W. trending axis. That the lake is pressed against the W. perimeter is consonant with this theory. Sand carried in by the river was blown up over many thousands of years by the persistent W. winds of the area to form the lunette on the E. side of Lake Victoria. Its position is a balancing of the water pressure against the W. perimeter and against the accumulating sand on the E. side. With the diminution of river flow into the basin, the lunette extended S. and cut off the water supply or forced the inlet channel S. so that water flowed only through the Frenchmans Cr. anabranch. Thus the present lake was established.

The genesis of the lake is far more complicated than this simplified account. The lunette had numerous alternating unstable (dune-building) and stable (soil-forming) phases. These can be divided into two periods represented by the Nulla Nulla and Talgarry Members of the Lake Victoria Sands which constitute the lunette (see section on stratigraphy). Some deep valleys were formed and a general depression of the dune morphology effected between emplacing the two Members. There was a marked change of fauna because large extinct marsupials characterize the Nulla Nulla Member while the modern fauna only occurs in the Talgarry Member.

The Lake Victoria lunette (for term see Hills 1940, discussed Gill 1964, p. 353, Campbell 1968, Macumber 1970) has an unusual morphology. More typical ones occur at Lake Wallawalla, S. of Lindsay Is. (Fig. 15), and Fletcher Lake, N. of Curlwaa.

The unusual character of the lunette lies in its great width and commonly horizontal bedding, which are related factors. Typical dune morphology from sand blowing up windward slopes, and spilling down lee slopes does occur, but more often the bedding is flat or near it. Similar structures occur in modern blowouts where sand is blown horizontally for great distances, then slides down a normal sandfall. It is therefore inferred that the supply of sand was inadequate in relation to the energy of the W. winds that provided the traction. Also as the sand was so fine, it was more easily moved. The periods of dune stabilization could therefore be due to:

1. Cut-off of sand supply (e.g. by change of river course),
2. Change in wind regime (considered unlikely) or
3. Increase in precipitation causing a stronger vegetative cover.

The factor yet to be explained in this theory of the genesis of Lake Victoria is what caused the river to divert to the NW. Attention is drawn to the large fault at depth below the E. side of Lake Victoria described in the section on tectonics. In this terrain of such exceptionally low declivities, a small movement on this fault could cause the river to be diverted. As the diversion occurred immediately after the

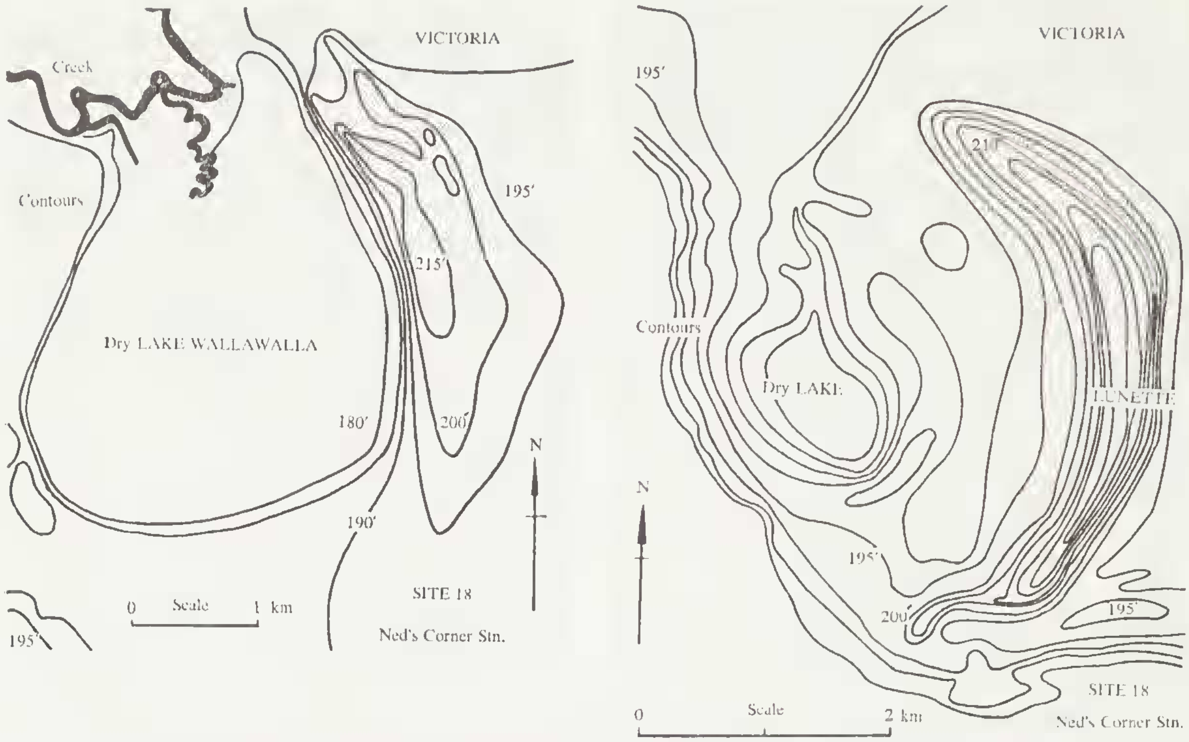


Fig. 15—Lake Wallawalla and an unnamed similar dry lake to the W. of it, both with lunettes. The age of these structures has not yet been determined. Based on Engineering and Water Supply Dept. (S.A.) Chowilla Dam map.

deposition of the Blanchetown Clay (i.e. just after the draining of Lake Bungunnia) a near horizontal lake-floor terrain would be present where the smallest tectonic disturbance would have a positive influence on the direction of river flow.

Lake Victoria Gulches

In this semi-arid country (22-25 cm rainfall) where rain seldom falls but may fall in quantity over a short period, a characteristic landform is the washout or gulch—short, steep and often deep valleys tending to vertical sides. It is comparable with the wadi of the Middle East, the arroyo of certain parts of North America, and such. The term "gully" is often used in Australia, but usually refers to an open, short valley in humid areas, where vertical sides are not usually found. Thus the term *gulch* has been chosen, and is used herein as defined above. Its derivation is from a Middle English word that meant to "swallow or devour greedily". Thus the Shorter Oxford Dictionary states that the word means "a narrow and deep ravine with steep sides marking the course of a torrent". Twice during our field work one third of the year's rainfall fell in one storm. Heavy rain in country of poor vegetative cover causes brief gushing torrents that rapidly corrade. This is particularly so since European settlement, which has often been accompanied by too heavy stocking. The first settlers came from a humid country, and did not understand this dry land.

Lunette Gulches

The most notable system of gulches in the area of study is that along the E. shore of Lake Victoria where the dune front has been severely eroded. These numerous gulches have provided important stratigraphic, pedologic, sedimentologic, archaeologic and palaeontologic data, and merit detailed study. Monash University Department of Zoology under Professor J. W.

Fig. 16—Map prepared from air photos of the gulch system in the lunette on the E. side of Lake Victoria, N.S.W. Fixing of fossil and other sites was difficult, so the gulches have been numbered N. and S. of the Nulla/Talgarry fence, the only permanent marker. Numbered pegs have been set at the heads of most of the gulches. Four deep concrete bench marks were inserted for fixing levels. As the lunette structures are subhorizontal (on the whole), vertical levels have significance.

Warren is continuing the study of the vertebrate fossils from this and other localities. With recurrent gulches of similar morphology, changing somewhat from year to year, we found it rather difficult to record sites so that they could be located again with speed and accuracy. It was therefore decided to number the gulches. As the only permanent mapped feature is the boundary fence between Nulla and Talgarry Stations, the gulches were numbered N. and S. of this line with appropriate N. or S. prefixes (Fig. 16). Over most of the lunette, square hardwood pegs 1·2 m long and with sides 5 cm wide were inserted at the gulch heads and the relevant number drilled by a series of holes into the leeward side. After two years they show no sign of deterioration. Four concrete benchmarks were also emplaced, and surveyed on to Chowilla Dam Survey pegs so that levels can be related to Murray River and sea level datums.

The morphology of the lake front is a wedge of sand blown up from the lake beach, modified by fans of outwash sand from the gulches. The morphology of the gulches varies. The ephemeral streams corrade steeply, tending to develop vertical walls. Wind erosion cuts deep blowouts with steep sides. This geometry is modified by rainwash, aeolian action and the activities of sheep, goats, rabbits and man. The reduced stability since settlement has made the area rather barren in contrast with the natural condition described by the discoverers. The hamada of outwash fans along the lunette above the beach appears to be recent. The sand slope was measured at 7°. About the middle of the E. shore (air photo CAC 37-5012 Lake Victoria run 5, 1954, 23 mm S. of E-W. line through CP) an auger hole was sunk 10 m from the water's edge on 25th Nov. 1969.

0·3 m Very pale brown 10 YR 7/3 (dry medium loose sand very poorly sorted, grading to
0·45 m Brown 7·5 YR 5/4 (moist) ditto grading to
0·6 m Damp ditto grading to
0·45+m Dark brown 7·5 YR 3/2 (wet) ditto.

The sand was uncompacted and water from the lake penetrated to the bore hole making further boring impossible with an auger. It was hoped to reach a carbonaceous former lake bed deposit that could be dated by radiocarbon.

(b) *West Bank Gulches*

The lunette gulches are mostly single channels (Fig. 16), 65% being so classifiable. Another 24% are simply branched, while the remaining 11% have multiple branches. It is a matter of interpretation which gulches go into which category, but these figures are of the correct order, and indicate a simple pattern of gulch formation. The erosion pattern on the W. bank is quite distinct, and the difference is a function of substrate. The lunette gulches are in fine sand with some clay, while the W. bank ones are eroded mostly in Blanchetown Clay and Chowilla Sand. From plateau level there is a steep slope from 10° to 30° then a lower slope to the lake edge.

Fig. 14 shows a tracing from air photos of these amphitheatres and the dendritic pattern of the gulches. Fig. 13 also shows a similar development on the N. bank of the lake W. of the "Old Hotel" (the site of an hotel belonging to the coaching days when this was a stopping place between Wentworth and Renmark).

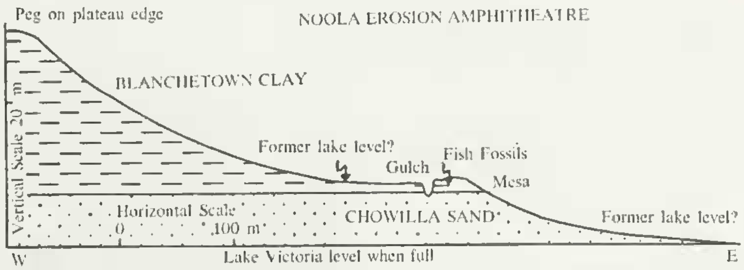


Fig. 17—Surveyed section of the Noola Erosion Amphitheatre, NW. shore of Lake Victoria, N.S.W. Site 6.

(c) *River System Gulches*

Gulches occur along the river banks (Murray, Darling and Anabranch), round some billabongs, and along creeks, such as Salt Creek and Six Mile Creek. Some of the best developed are on the E. side of Salt Creek on Kulcurna Station. One had such bright oxidation colours that we called it Kaleidoscope Gulch. One gulch N. of this was characterized by a cirque-like head. In this area, the silicified Chowilla Sand forms a lower plateau level as at Cal Lal. This zone is resistant to erosion so deeper gulches with steeper sides result. Pieces of the silicified sand block the gulch floor in places. This rock contains rhizomorphs up to 5 cm diameter. The indurated zone forms a shallow syncline, which causes variation in the depth of the gulches.

Gulches round Triple Swamp have yielded dolomite, fossil bones and Aboriginal sites as well as extensive stratigraphic information as recorded later in this paper. Much of the information discovered is due to the development of this feature. As every heavy rain gouges them out a little more, fresh sections are always available.

Stratigraphy

> *Geologists "first tracked mud and heresy into the schools of learning 200 years ago"*. Fuller (1971)

1. *Standard section*

In connection with the proposed Chowilla Dam, bores were sunk across the Murray River valley at a site between Renmark, S.A., and the Victorian border (Figs. 1, 4). J. B. Firman studied the geology and prepared a report which has not been released. However, a summary of the stratigraphy has been published (Firman 1966, 1967). Firman kindly provided a copy of his cross-section (Reproduced in Fig. 18) and this well-attested profile is here used as a standard section. For the present purpose, the following are noted:

(a) *Superposition*

The succession is simple, so the relative ages are clear.

(b) *Tectonism*

After the Parilla Sand was deposited, earth movements belonging to the Kosciusko Epoch caused uplift of the Pinnaroo Block (=Murray Ridge of earlier writers), damming the Tertiary river drainage, and so causing deposition of the Blanchetown Clay. Later, penetration of this natural barrage led to downcutting and excavation of the broad (4·8 km) gorge (so called because of depth and steep to vertical banks) into the Blanchetown Clay, Chowilla Sand, Parilla Sand, and Loxton Sands.

A disconformity thus exists between the Tertiary Loxton Sands and the Late Quaternary Monoman and Coonambidgal Formations.

(c) *Palaeoecology*

The Murray Basin has a succession of Tertiary marine strata (Fig. 3), the latest of which in our study area is the Bookpurnong Formation, which was also encountered in a well excavation (Tate 1899) on Tareena Station (Fig. 4), and in all the oil bores (Fig. 3). The succession of facies with time (i.e. upwards through the section) portrays the retreat of the sea from the Murray Basin, viz:

Parilla Sand (clayey)	Riverine floodplain
Chowilla Sand (well washed)	Riverine channel
Blanchetown Clay	Lacustrine
Loxton Sand	Estuarine
Bookpurnong Formation	Marine (shallow water)
Pata Limestone	Marine (shelf)

With this principle of facial succession established, one would expect to find a similar succession throughout our limited area of study, and this appears to be so. The A.O.G. Wentworth No. 1 Bore (40 km N. of that town) revealed Loxton Sands or equivalent at 52·5-80·5 m and Bookpurnong Formation below that to 109·1 m.

The A. O. G. Lake Victoria No. 1 Bore (at the S. end of the lake) penetrated "typical" Bookpurnong Formation from 93·9-113·4 m "with a rich microfauna". Above this are "pyritic sands with carbonized wood fragments and fish bones", which might be estuarine and the equivalent of the Loxton Sands. They are similar to the sediments in the Wentworth Bore at that stratigraphic level. The A. O. G. North Renmark No. 1 Bore (about 8 km N. of that town, near the corner of the Ral Ral Ave. and the Wentworth Road) encountered Loxton Sands from 18·3-42·7 m. Bookpurnong sediments were reported from 42·7-61 m. Thus in all three bores the Bookpurnong Formation is adequately defined but the Loxton Sands are proven only in the Renmark Bore. Even there, definitive fossils (small foraminifera, echinoid spines and molluscan fragments) occur only in the lowest 3 m. So perhaps the sediments in the other bores are riverine equivalents of the estuarine Loxton Sands.

(d) *Structure*

The strata (including the non-marine) in the standard section are superposed in a regular manner with subparallel surfaces. This regularity does not continue in the non-marine formations of the study area to the east. For example, the Chowilla Sand does not maintain the fixed stratigraphic position it possesses on the Pinnaroo Block. On the contrary, it appears below the Blanchetown Clay, within it, or above it, or any combination of those. Thus E. of the Pinnaroo Block it is a facies indicator, and no longer a stratigraphic marker.

Structure E. of the Chowilla Dam site can be defined by the highest indubitably determined stratigraphic horizon in the A.O.G. section (Fig. 3), viz. the base of the Bookpurnong Formation. Adjusting the levels to the sealevel datum, the results are:

Renmark Bore	37·4 m
Lake Victoria Bore	83·7 m
Wentworth Bore	69·5 m

In compensation for the uplift of the Pinnaroo Block, the strata to the east sagged, and the resultant structure is here called the *Lake Victoria Syncline*. As this syncline was due to upthrust of the crustal block to the W., the mild fold is understandably asymmetric with a lower dip on the E. flank. The openness of this syncline is in keeping with the minitectonics (for term see Gill 1972) of the area. The Lake Victoria syncline explains why:

I. The Parilla Sand, although a well characterised formation disappears below river level east of Kulcurna Station. As far as I have been able to check the stratigraphy, it does not reappear until the Paringi area 29 km SE. of Mildura.

II. The characteristic interdigitation of the formations upstream from the dam site, i.e. within the syncline. The Pinnaroo Block constituted a natural dam, and created a temporary or structural base level (Chorley and Beckinsale 1968). However, the gross interdigitation means that the lake so formed was not one large sheet of water that persisted over the whole area throughout the period of impedence to river flow, but rather a fluctuating series of lakes and swamps across which river channels kept changing. The high evaporation no doubt had much to do with this. Widespread beds of dolomite developed at one time, and in some areas these were eroded before deposition continued, while in others the very fine dolomite was mixed with sand. As would be expected, the most continuous lacustrine conditions prevailed near the damming Pinnaroo Block. Thus the thickest sequence of Blanchetown Clay can be seen along the Murray River at Lake Victoria (Warrakoo) and Nampoo Stations (Fig. 4).

2. *Regional Formations*

The formations consist almost entirely of low dynamics sediments, comprising clays to fine sands. This applies to both the aeolian and riverine formations, because the former are derived from the latter. The coarse fractions of the originating streams are trapped in the E. side of the Murray Basin because the traction was not available in this flat country to bring them further W. Significant in the stratigraphy therefore are:

(a) The presence of any gravels, as they are so rare.

(b) The change from sand to clay, and vice versa.

(c) The change from clayey sand (floodplain) to well-washed sand (channel) deposits.

(d) The presence of dolomite and limestone, because they indicate special sedimentary conditions.

(e) The presence of paleosols because they indicate a cessation of sedimentation, a time-break, and an absence of water or other such cover. They indicate also a period of stability, and the extent to which the subaerial agencies could leach (and otherwise alter) the surface of the terrain. The nature of the minerals removed or mobilised indicates the prevailing geochemical conditions, which have implications with respect to the vegetative cover and fauna.

The paleosols are described in an accompanying paper on palaeopedology.

The formations will now be briefly described from oldest to youngest.

(a) *Bookpurnong Formation* (Figs. 3, 18). This is the youngest of the marine formations; it extends throughout the studied area. It is therefore used as a stratigraphic and chronologic datum. Questions of chronology will be dealt with in the section on that subject. Although it does not outcrop at the surface it was

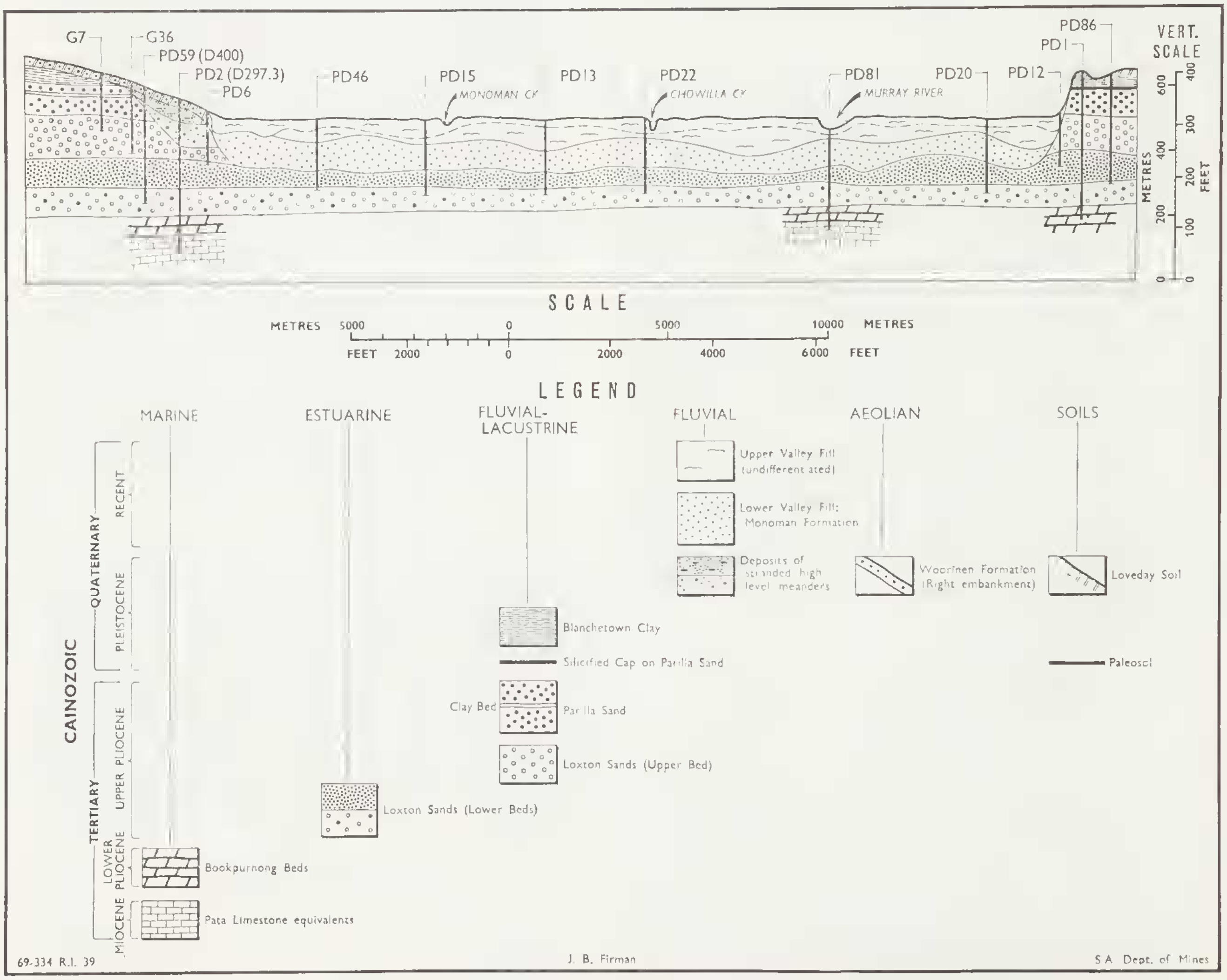


Fig. 18—Standard stratigraphic section at the proposed Chowilla Dam site, by courtesy of the S.A. Dept. Mines. Site 1.

encountered in a well on Tareena Station and can be followed in the three A.O.G. bores. For lithology and palaeontology see Ludbrook et al. 1958, Ludbrook 1961, 1969, Firman 1966, 1967.

(b) *Loxton Sands* (Figs. 3, 18). This formation of fossiliferous estuarine sands forms the cliffs at Loxton, S.A., is present at the base of the Chowilla Dam section (Fig. 18), occurs in the Renmark bore (Fig. 3), but appears to grade into a riverine facies further E.

The succeeding formations occur in the Lake Victoria syncline in river and lake bank outcrops:

(c) *Parilla Sand* (Figs. 4, 18-20). The gray compact clayey sand, with a vertical cleavage is very consistent and easily recognized. Where cliffs are undercut in river or gulch it forms vertical faces, and where not it forms steep rilled slopes. The section on the right bank of the River Murray at Kulcurna Station just downstream from the homestead is unusual in that it consists of only two formations—Parilla Sand surmounted by Chowilla Sand (Fig. 19). A similar thickness occurs on the S. bank of the River Murray at Boundary Point (Victoria/SA. boundary). The cliff was measured nearest the homestead where it is lower but more accessible, viz.:

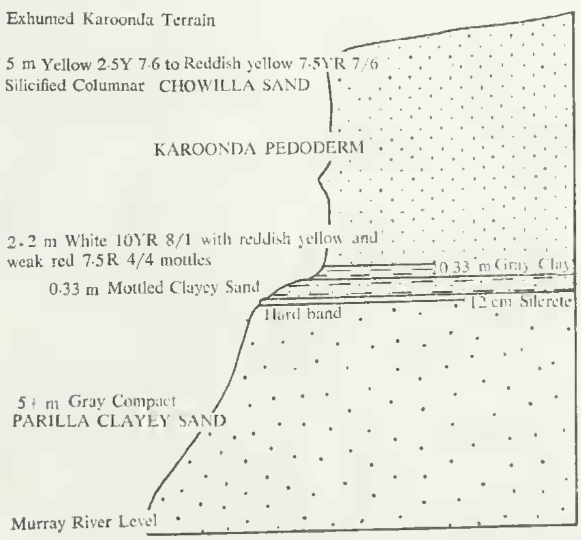


Fig. 19—Measured section of cliffs beside Kulcurna Station homestead, Cal Lal, N.S.W. Right bank of Murray River. Site 3.

5m	Yellow (2·5 YR 7/6, and variants) to reddish yellow (7·5 YR 7/6) lightly silicified columnar sandstone forming vertical cliff Chowilla Sand
2·2m	Mostly white (10 YR 8/1) silicified sandstone with reddish yellow and weak red (7·5 R 4/4) mottles; rhizomorphs, and silicified burrows. The top of this bed is more silicified than elsewhere, and forms the upper hard band seen in the cliffs. Similar horizons occur at Salt Cr. and the Chowilla Dam site—Chowilla Sand.
0·33m	Black to gray clay. Causes change in cliff slope. Recognizable on inaccessible faces of the cliff by course cracking. Minute crystals of gypsum on some joint planes
0·33m	Mottled gray, light brown and red clayey sand with fine cracking.
0·15m	Platey silcrete in one to six layers. Material suitable in places for Aboriginal implements. This forms the lower hard layer seen round the cliffs
5 + m	Compact gray (10 YR 5/1) clayey sand—Parilla Sand.
13·01m	

The thick lightly silicified columnar sand reminded the author of a similar deposit above kaolin in the Home Rule pit near Gulgong, N.S.W. The white sand at the base of the Chowilla Sand varies in thickness. The formation is an aquifer while the underlying Parilla clayey sand is an aquiclude, so the whiteness may be a function of leaching along the base of the aquifer. There is a sharp boundary to the underlying clay, so the ancient river spread sand over a lagoon or swamp. The clayey sands are interpreted as a floodplain deposit and the well-washed sands above as a channel deposit. The clean sands readily admitted air, and so are oxidized.

The degree of silicification varies greatly. It is less near the mouth of Salt Creek so that loose sand has blown up to form the eminence called Mt. Hancock. At the N. end of the Salt Creek cliff is silcrete, that when free to vibrate rings like a bell if struck.

At the outlet of Salt Creek and for a short distance upstream the section is essentially as above. Then the Blanchetown Clay comes in, and a measured section marked by a peg at the S. end of Scrub Paddock is as shown in Fig. 20, viz:

4·1m	Red Bunyip (?) Sand
2·1m	Red and yellow silicified Chowilla Sand
1·2m	White ditto

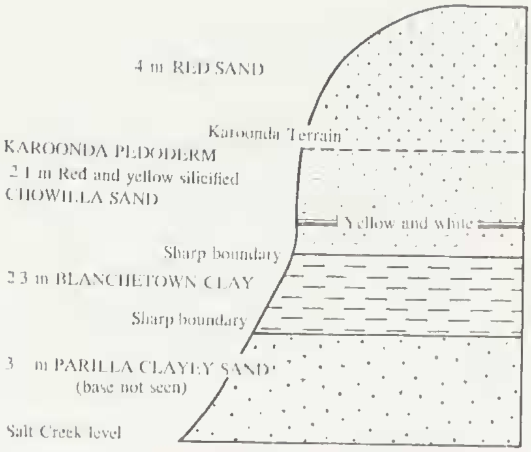


Fig. 20—Measured section on E. bank of Salt Creek, Kulcurna Station, N.S.W., at the S. end of Scrub Paddock. Site 2.

2·3m Green Blanchetown Clay
3·0m + Gray compacted clayey Parilla Sand 8·3m to creek level covered by talus

Firman (1966, 1967a,b, 1971) gives the Parilla Sand as the equivalent, at least in part, of the marine Norwest Bend Formation. The 1972 S.A. Department of Mines map of surficial deposits in the Murray Basin shows a succession of ecologies in the formations as they appear from W. to E. on the Murray River from Morgan to the Victorian border, viz.:
Morgan Limestone (marine shelf)—Loxton Sands (Estuarine)—Parilla Sand (Riverine)—Blanchetown Clay (lacustrine).

The formations are thus younger from W. to E., and pass from marine to terrestrial from W. to E. In the study area the Parilla Sand is overlain (with a sharp break) by either Blanchetown Clay or Chowilla Sand. In some places there is evidence of slight erosion on the top of the Parilla Sand, but in general the top of the formation is remarkably horizontal.

The Murray River cliffs between Paringa and Loxton, S.A., show excellent outcrops of Parilla Sand. For example, where the Sturt Highway meets the cliffs 2·4 km NW. of the Loxton turnoff (12 km from Renmark) near a parking bay, the Parilla Sand constitutes approximately the lower half of the cliff (Pl. 2 fig. 1, Pl. 6, fig. 1). The Parilla Sand can be seen to continue for some kilometres along the cliffs, but it cuts out E. of Salt Cr. (Kulcurna Stn.). Pl. 8, fig. 2 shows the occurrence there with its typical vertical cleavage and rills.

Parilla Sand (Fig. 18) is the main cliff outcrop on both banks of the Murray River at the Chowilla Dam site (Pl. 2, fig. 2). The top of the formation is marked by a bench consisting of the silicified materials of a paleosol (see paper on palaeopedology). The top of this fossil soil is the Karoonda Surface (Firman 1967) or Terrain.

The formation is named after the town of Parilla in S. Australia (Firman 1971 and references). Firman (1971, p. 62) claimed that the Parilla Sand could be traced "as far upstream as Nyah in Victoria". In this *Memoir* Parilla Sand is retained in its original definition, and the very varied sediments lying immediately below the Blanchetown Clay (except Chowilla Sand) in the Lake Victoria Syncline are described as the Moorna Formation. Parilla Sand probably occurs below this. The uplift of the Pinnaroo Block occurred in post-Parilla time, and earlier than the deposition of the Blanchetown Clay.

(d) *Blanchetown Clay*. Firman (1965, 1971) provides the origin of this stratigraphic name and maps the extent of the formation in S. Australia. The type section is on the left bank of the Murray River 4·8 km below Blanchetown in S. Australia. The formation is distributed "North and east of the Pinnaroo Block" (Firman 1971, p. 54). It may be described as the most characteristic formation of the study area. On present knowledge, the thickest outcrops are in the River Murray cliffs on Warrakoo and Nampoo Stations and on the banks of Lake Victoria, i.e. in the Lake Victoria syncline. The formation thins out to the east (Fig. 36) but continues at least as far as Robinvale, where Blanchetown Clay outcrops in the river cliffs. The lithology is typically a greenish gray claystone to siltstone. A. J. Gaskin, C.S.I.R.O., suggested that the green colour is due to ferrous iron in the lattice. As may be expected, the clays grade in places to sandy phases. See Segnit, this *Memoir*.

Figure 21 is a measured section E. of Nampoo Station homestead on the W. side of a track down the cliff to river level. At this

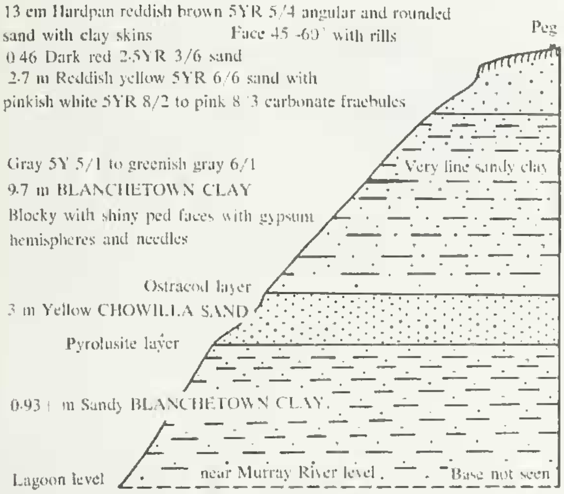


Fig.21—Measured section of cliff on the E. side of Nampoo Station homestead beside track to river level. Site 4.

point the section is about 22 m thick, but W. of the homestead the cliffs are 36·6 m high and the surficial reddish horizon is 6·4 m thick where measured. This consists of reddish brown and greenish mottled clayey sand with thick calcrete-bearing soil at the top. These sediments are interpreted as altered Blanchetown Clay. Whether the Blanchetown Clay continues below the river level is not known. For the present the whole Nampoo section at Sharp Point 36·6 m thick, is referred to the Blanchetown Clay. The dolomite members in it will be discussed later. There are intercalated bands of sand and clayey sand. The lowest bed could be Moorna Formation.

The top of the section near the track was examined in more detail, and the following information obtained:

- 12·7cm Reddish-brown (5 YR 5/4) angular and rounded sand with fine clay skins forming a hardpan (Al horizon removed by erosion). The hardpan tends to form verticle edges on the cliff and is columnar. Penetrometer 0·2 kg/sq cm merging rapidly to
- 46cm Dark red similar sand (2·5 YR 3/6), blocky and forming a slope of 45°-60° with rills. Penetrometer varied round 1kg/sq cm
- 2·7m Reddish yellow (5 YR 6/6 but varying with amount of carbonate and faint mottling) sand. Numerous carbonate nodules, pinkish white (5 YR 8/2) to pink (8/3). Boundary distinct
- 9·7m Gray (5 YR 5/1) to greenish gray (5GY 6/1) claystone, blocky with shiny ped faces (secondary clay). Gypsum crystals in form of hemispheres and needles (Blanchetown Clay)

Slip material covers the rest of this section, but W. of it 60 cm of Chowilla Sand (Pl. 7, fig. 2) underlies Blanchetown Clay (Pl. 7, fig. 1) with a thin ostracod layer at the base of the latter. Below the Chowilla Sand is 2·5 m of clayey sand, the top of which has undergone varying degrees of silicification, interpreted as a function of the Karoonda surface pedogenesis. The maximum is a hard band nearly a metre thick that stands out firmly on the cliff profile. E. of the homestead the ground surface slopes down to near river level where a gulch cuts the cliff. Here a thick silicified layer has been quarried. In the gulch a 12 cm band above the sandy layer is crowded with ostracods. Determinations of fossils are given in the section on palaeontology.

Roberts (1968) has provided information on this formation gained by drilling in the Waikerie district, S.A. He suggests that the Blanchetown Clay was once over 24 m thick there, but has since been eroded. The Bungunnia Limestone occurs capping the Clay on two of the three hills of clay buried under aeolian sand, but it also occurs in one of the low areas. Thus either the limestone is not one stratum laid horizontally, or it has been faulted (which seems unlikely).

The Blanchetown Clay is sparsely fossiliferous. At Warrakoo (Lake Victoria) Station (Fig. 4) NE. of the homestead, the high steep cliffs have two harder bands in this formation near the top. They consist of siltstone and where laminated contain in places soft plants with simple branching, which are apparently water plants. Ostracods are the commonest fossils, usually crowding bands 5-15 cm thick. Generally, these layers are at the base of the clay deposit following a sharp boundary from sand, suggesting shallow waters. However, they also occur in lenticles in the mass of the formation. When examining the thick exposure of Blanchetown Clay on the N. bank of the Murray River at Sharp Point W. of the Nampoo Station homestead, I saw what appeared like pieces of tissue paper. Examination under a lens showed that they were a layer of ostracods one shell thick. The layer was then found in place.

Mollusca have been found only in a brown sandy clay at the N. end of the large erosion amphitheatre on Noola Station (Fig. 14). On the N. wall of the N. gulch complex thousands of small *Corbicula* occur with all sizes from young to adult. The bed outcrops in three gulches and the separating interfluves over an area approximately 60 m by 30 m. The valves are rarely together and are poorly oriented. They are reminiscent of the banks of similar shells found now on the floor of Lake Menindee (on the Darling River system, used as a reservoir) when it is dry. A similar lens was seen further S. in the same erosion amphitheatre on Noola Station.

Fish spines, vertebrae and other fragments were found in the same area in the Blanchetown Clay and in sandy bands included therein. Oblique burrows about 0·3 cm diameter were noted in the latter. At Bone Gulch on Moorna Station bones of a large marsupial were discovered in the base of the Blanchetown Clay.

At Triple Swamp (Fig. 22) on Moorna Station is a gulch with beds of dolomite to be described later in this section. On the E. side of Triple Swamp gulch are two beds of dolomite in Blanchetown Clay, as shown in Fig. 23. The cliff is almost vertical and the face between the two dolomite beds slightly concave. A pebble of milky quartz about 18 mm by 8 mm was found in the position indicated in Fig. 23. (See also Pl. 8, fig. 1). It is very well

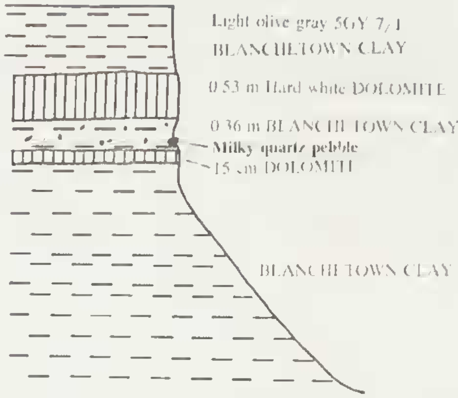


Fig. 23—Occurrence of pebble in clay sediments at Dolomite Gulch, Triple Swamp (Fig. 22), Moorna Station, W. of Wentworth, N.S.W. Site 12.

rounded and has a slight polish. Also it is completely out of character with its enclosing matrix which is clay, the sediment of the lowest dynamics of all. The pebble was indubitably in situ. The narrow end was protruding, it was more than half buried, and had to be dug out of the hard clay. A fine layer of secondary minerals lined the cavity from which it was taken. For example, pyrolusite was on the wall of the cavity and in corresponding places on the pebble. As the pebble is sedimentationally out of place, it could only have reached this position by being floated in. Pebbles of this size are almost unknown in this region of low declivities and fine sediments. For this and other reasons it is unlikely to be a drop pebble from a floating stump. The most probable explanation is that the stone is a gastrolith from a large bird or reptile. On the interpretation of the dolomite given in this *Memoir* the water would be shallow, but even if deep the pebble could be from a floating cadaver. Many smooth pebbles found on clay pans at the present time appear to be explicable only as gastroliths, and are probably from emus.

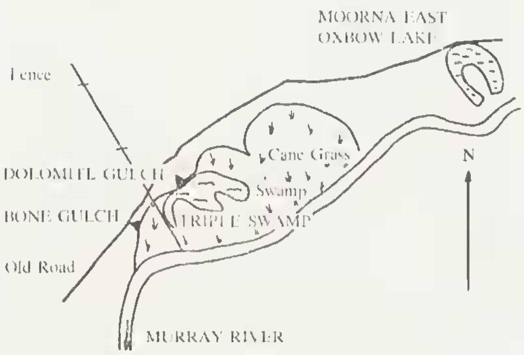


Fig. 22—Map of localities—Moorna E. oxbow, Triple Swamp, and Bone Gulch. Traced from air photo Moorna Station, W. of Wentworth, N.S.W. Site 12.

(e) *Blanchetown Clay, Dolomite and Limestone Members*

Triple Swamp (Pl. 9, fig. 1) is a flat swampland that is covered by Murray River floods. The sediments are greenish gray clayey sands to sandy clays referable to the Coonam-

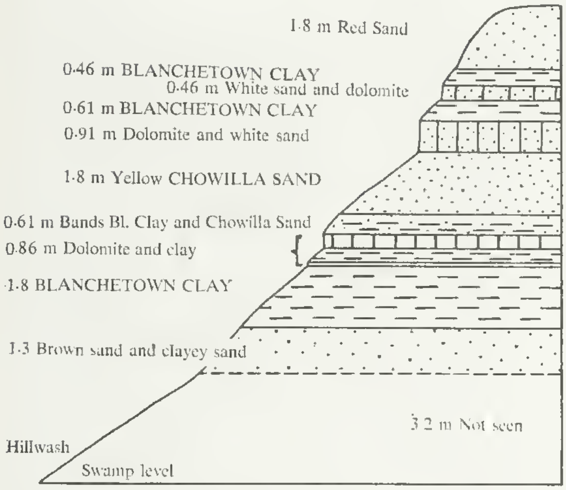


Fig. 24—Measured stratigraphic section at Dolomite Gulch (Fig. 22), Moorna Station, W. of Wentworth, N.S.W. Site 12.

bidgal Formation. This canegrass swamp dries out and cracks deeply in summer. In places there are sand rises with *Eucalyptus largiflorens*. The cliffs behind permit one to view a long section of the stratigraphy which consists of Blanchetown Clay and Chowilla Sand, but with many variations. The cliffs in the vicinity of Triple Swamp Gulch are unusual in that three white layers (Pl. 9, fig. 2) glare in the strong sunlight of this semi-arid region. The white rock is dolomite, pure in some places, and sandy in others. These white layers stand out against the red soil at the top of the section and the greenish gray (5 GY 6/4, 7/1) to gray (5 Y 6/2) Blanchetown Clay. The dolomites are dense and so stand out in the cliffs (Pl. 8, fig. 1). In the gulches they form vertical faces. The rock was too hard for the penetrometer used, but the Blanchetown Clay gave readings of 16-20 kg/sq cm. The red sand at the top of the cliff gave 4-8 kg/sq cm. and the topsoil 2-4 kg/sq cm. The topsoil is a later addition here because an Aboriginal midden was found between the A and B horizons.

A second striking occurrence of dolomite is found at Sharp Point on the N. bank of the River Murray at Nampoo Station. Here again, the beds lens out, but nevertheless reach a maximal thickness of 1·2 m. Here too, there is association in places with sand. The succession and variation is shown diagrammatically in Fig. 25. On the other hand, there is a difference in that opal is associated with the two dolomite layers at Nampoo. The two layers cut out to the E. then a 1·2 m band appears near the Nampoo pump, cuts out then reappears further E. as a sandy dolomite to dolomitic sand. Silcrete is associated with the sand and not opal. There is a slight dip to the E. (1 in 400), and it could be that the second dolomite band is hid from sight to the E. The changes to the W. are shown in Fig. 25.

Messrs. Sharp and Howells Pty. Ltd. obliged with an analysis of dolomite from the lower layer at Sharp Point, with this result:

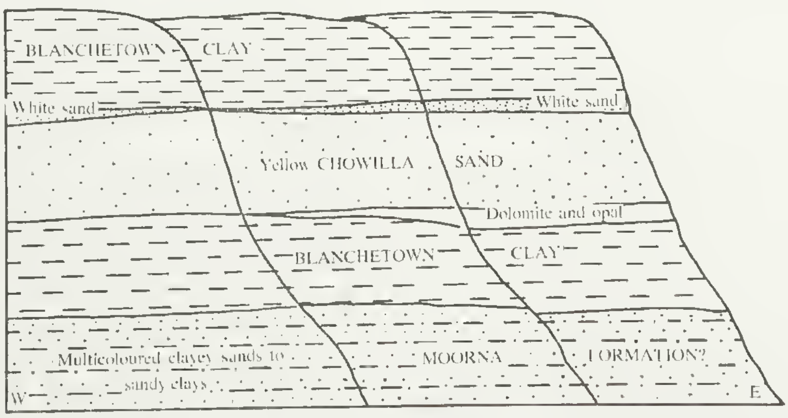


Fig. 25—Sketch of successive headlands in dissected cliff at Sharp Point (Devil's Elbow), Nampoo Station, E. of Cal Lal, N.S.W. (Fig. 4). N. bank of Murray River. Site 4.

$CaCO_3$	54·5 per cent
$MgCO_3$	42·5
Silica etc. by difference	3·0
	100.0%

Dr. E. R. Segnit (as reported in a paper in this *Memoir*) made X-ray and D.T.A. analyses of the dolomites. He determined cristabolite and tridymite. The opal beds have caused a change in slope of the cliffs at Sharp Point and resulted in a small headland jutting into the river. This more resistant rock has resulted in a very sharp turn in the river here, hence the name. Early river pilots called it the Devil's Elbow. A section of the little headland is given in Fig. 26.

While the whitish sand below the Chowilla Sand is shown as horizontal, it is disturbed in places as much as 15°, apparently by the churning of the clays. Slickensides are common in this zone. These relationships are shown in the field sketch made at Sharp Point reproduced in Fig. 27.

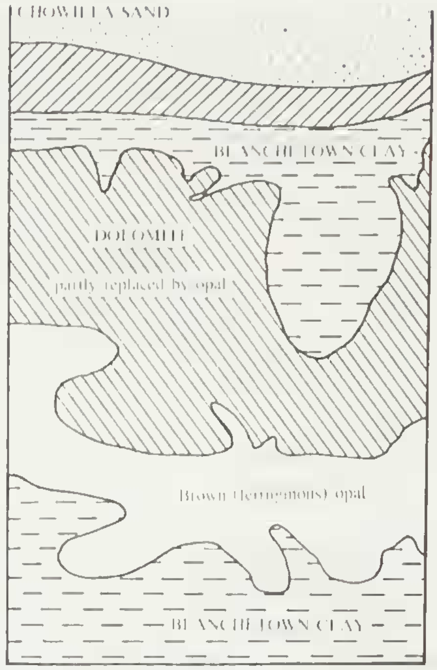


Fig. 27—Interpretation of dolomite and clay at Sharp Point, Nampoo Station, E. of Cal Lal, N.S.W. Much of the dolomite has been replaced by opal. Site 4.

The opal occurs both in masses as shown in Fig. 27, and in nodules which are generally bulbous but with some little sharp points at irregular intervals on the surface, which is white. The upper dolomite bed at Sharp Point has massive rock, replaced to varying degrees by opal, brecciated (and recemented) opalized dolomite and nodules. The opal is a highly vitreous translucent (clear, brownish, bluish, pinkish) to opaque (mostly brown). Just above the upper opal bed is a finely laminated band (0·6 cm thick) rich in ostracods. Laterally, this opalized dolomite becomes in places a silicified sandstone.

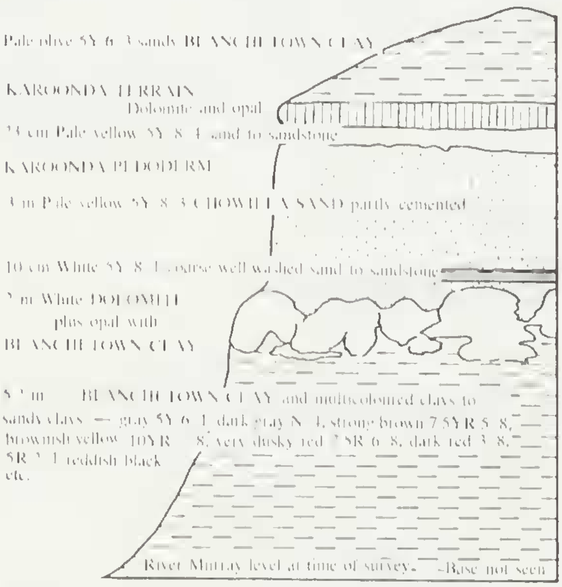


Fig. 26—Measured section at Sharp Point, Nampoo Station, E. of Cal Lal, N.S.W. N. bank of Murray River. Site 4.

The opal/silica deposits are regarded as pedogenic. The Chowilla Sand below the upper dolomite layer is mottled. The clayey sand below the lower layer is also mottled and contains rhizomorphs of quartz plus opal (E. R. Segnit det.) There is often silicification without opal at the same stratigraphic horizon as at Cal Lal, the Murray River cliffs at Kulcurna Homestead, on Salt Creek and elsewhere. On Salt Creek opal is deposited in Blanchetown Clay but in the same cliff at the same horizon only

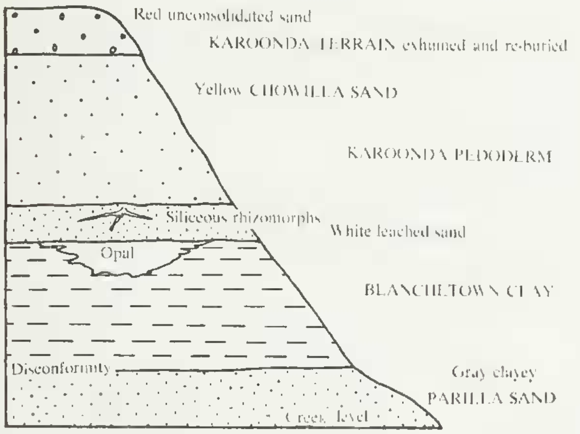


Fig. 28—Section of E. bank of Salt Creek towards the S. end, on Kulcurna Station, Cal Lal, N.S.W. Site 2.

10 m away where sand has replaced the clay, silcrete is deposited. Also sand just above the opal has rhizomorphs, as shown in Fig. 28. In some of the gulches at the S. end of Salt Creek, masses of silicified sandstone have fallen to the floor of the gulch and these provide an excellent opportunity for studying the branching rhizomorphs. There are also burrows, which are not branched, do not vary in diameter, and have some kind of segmentation of the infill.

Although no dolomite layer was noted in the Salt Creek section, a bore put down E. of the creek in connection with a salinity survey penetrated a dense fine-grained rock. By the time I examined the site, none remained, but Mr. Hans Hansen of Kulcurna Station told me that it appeared the same to him as a lens of dolomitic rock (which he kindly drew to my attention) on the cliff behind Kulcurna Homestead. For relation to Salt Cr. see Fig. 4.

The dolomite has suffered minor erosion in some places, while at others it remains only as fragments in sediments. The former is illustrated by Fig. 29 which shows a section on Nampoo Station E. of Sharp Point. Fragmental remains can be illustrated by the W. end of Fishermans Cliff section (Fig. 30) where pieces of gravel in the Moorna Formation are covered with white coatings. These worn coatings drew attention because they looked like calcium carbonate and so the first appearance of the present semi-arid climate that amasses such carbon-

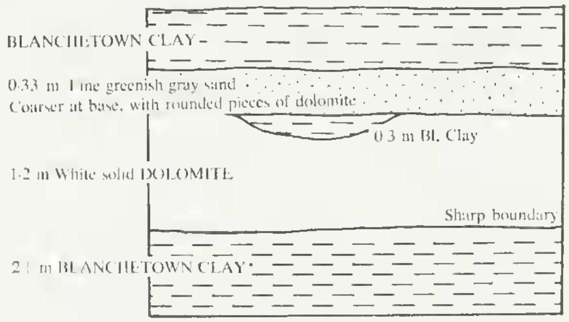


Fig. 29—Section in cliff at Nampoo Station homestead pump, E. of Cal Lal, N.S.W., providing evidence of erosion of dolomite. Site 4.

ate. However, Dr. Segnit identified the mineral by X-ray as dolomite, so a gravelly dolomite must have been formed then eroded to provide this sediment. Carbonates are so abundant in this climate that almost any rock effervesces on application of cold acid (as did the dolomite) so this field test can be misleading. At the E. end of Fishermans Cliff the section is as in Fig. 31. A layer 0·6 cm thick, 0·6 m below the top of the Moorna Formation, has small

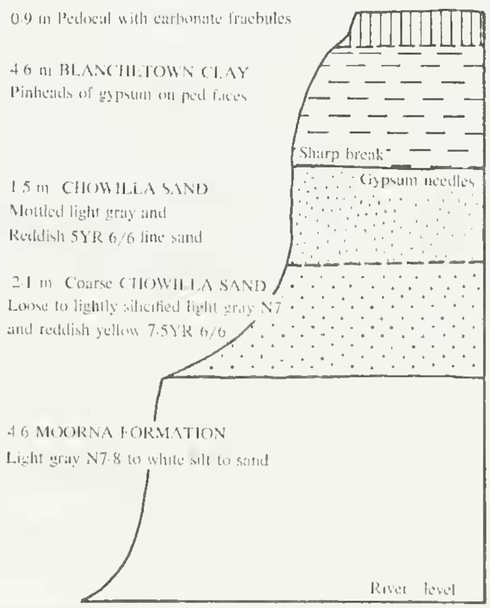


Fig. 30—Surveyed section W. end of Fisherman's Cliff, Moorna Station, W. of Wentworth, N.S.W. N. bank of Murray River. See Fig. 31 for E. end. Site 13.

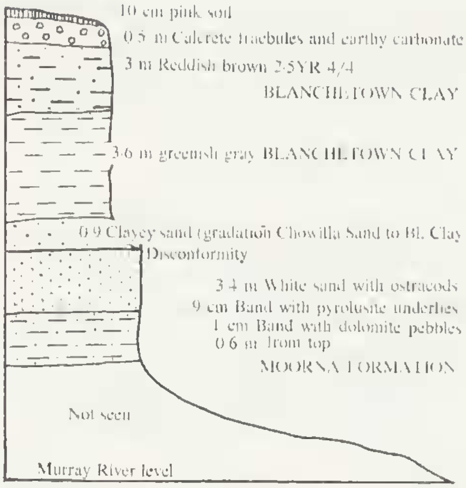


Fig. 31—Measured section at the E. end of Fisherman's Cliff, Moorna Station, W. of Wentworth, N.S.W. Lateral differentiation can be seen by comparing this section with that from the W. end (Fig. 30). Site 13.

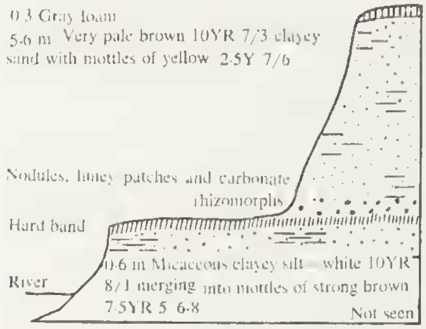


Fig. 32—Measured section on N. bank of the River Murray, Tammit Station, 16 km from Euston, N.S.W., in the Sandhills Paddock. The carbonate is dolomite.

rounded to angular pebbles of dolomite. Just below this band is one rich in pyrolusite about 8 cm thick. The same detrital dolomite band associated with pyrolusite occurs to the NE. in the gulch at the NW. corner of Moorna Oxbow lake. So the dolomite was once more widespread than appears by present outcrops. In a rapid reconnaissance of the Murray River upstream from the study area, dolomite (E. R. Segnit det.) was found on Tammit Station about 14·5 km from Euston. In the Sandhills Paddock about 16 km WSW. of the homestead, Mr. O. Grayson showed me the section given in Fig. 32, where the right bank of the Murray River reveals:

0·3m	Gray loam
5·5m	Very pale brown 10 YR 7/3, with yellow mottles 2·5 YR 7/6 clayey sand. At base, rhizomorphs, carbonate patches, and dolomite nodules forming a berm in river bank
0·6m	Micaceous clayey silt, white 10 YR 8/1 merging into mottles of strong brown 7·5 YR 5/6-8
1 + m	Clayey sand with iron oxide mottles, becoming ironstone in places. Forms reef at Tammit homestead.

Similar sections were seen in other places on the river in this area.

Firman (1966, 1971a) has described the Bungunnia Limestone in S. Australia as a formation succeeding the Blanchetown Clay and occurring E. of the Morgan fault line scarps, also W., N. and NE. of the Pinnaroo Block. It is a "micrite flaggy or banded, oomicrite, oolitic algal biolithite, calcilutite; generally dolomitic and containing ostracodes". This formation does not occur in the study area, but there are lenses of similar lithology in the Blanchetown Clay. They are related to the Nampoo and Triple Swamp dolomite members but are lithologically distinct. The members described above are pure white dolomite, extremely fine in texture (Segnit, *et al.* this *Memoir*)), and no fossils have yet been found in them. By contrast the Bone Gulch dolomite member and the Morkalla dolomitic limestone member are light brown, much harder rocks (the latter is used for paving paths) and highly fossiliferous, being packed with ostracods and other evidence of biologic activity.

On the W. side of Bone Gulch on Moorna Station, N.S.W., erosion has stripped Blanchetown Clay from the top of the dolomite which in turn has protected mottled Blanchetown Clay below it. The rock is pale brown, whitish or pinkish in places, and of low specific gravity, due to the large numbers of ostracods *(Ilyocypris, Candona* and *Diacypris)*. The bed is only 1·3 cm to 5·4 cm thick, but extends 140 m along the river, and intermittently for another 60 m. As the deposit has been eroded by the Murray River, its original extent is not known. The deposit indicates shallow lacustrine conditions. It is sandy in places. The ostracods are dolomitized, so secondary dolomitization is involved. The matrix is olive gray 5 Y 6/2 and the mottles reddish-brown 2·5 YR 5/4 and white 7·5 YR N8. The white is due to gypsum crystals and carbonate. Rosettes of gypsum up to 12.5 cm occur but most of this mineral is in small pieces 0·5-2·5 cm diameter. The clay becomes greener with depth. Professor R. H. Tedford described (in litt.) "ostracod coquinas" in the water supply canal cut between Lake Pamamaroo and Lake Menindee to the N., and others are reported elsewhere in this paper.

In the Morkalla district of NW. Victoria are the properties of Messrs. B. Nunn, R. and L. Gray, and F. Heitmann which have on them flaggy dolomitic ostracodal limestone. Where thick enough, and near enough to the surface, it is ripped up with a tractor and sold for making ornamental paths. Dams on the Nunn property show clay which is probably Blanchetown Clay. On the Old Station dam on Grays' property, limestone is reported at 2·5 m with clay above. About 1·5 km WSW. of L. Grays' house (Pl. 8, fig. 3) just E. of a N-S. fence and S. of an E-W. fence, a scour showed ostracodal limestone in situ (Pl. 8, fig. 4). At this site it is horizontal and in three layers over a marly clay. The limestone is a light greenish colour inside and off-white on the outside. A section was measured as follows:

5cm	Red sand and small pieces of calcrete (hill-wash)
2cm	Layer 1 of limestone, crazed on top
1·9cm	Layer 2
1cm	Layer 3
40 + cm	Mottled green, white and reddish brown clay to clayey marl

The limestone was followed round the base of a red sand ridge at the same contour for 1·5-2 km, indicating that the deposit is horizontal and probably extensive.

(e) *Chowilla Sand*

The Blanchetown Clay (Pl. 7) and the Chowilla Sand (Pl. 6, fig. 1) are the two most characteristic formations of the study area, but they contrast strongly. The former is predominantly clay, while the latter is predominantly quartz, usually well-washed. The former is a low dynamics lacustrine sediment, while the latter is a riverine channel deposit. Similar deposits occur in the Holocene Coonambidgal Formation where the loose channel sands provide the source for the structuring of channel border dunes. There are parts of the river at present where the dynamics are such as to wash clay from sand and provide sufficient of the latter to build limited beaches and dunes, e.g. in the Mildura area. The Blanchetown Clay and the Chowilla sand interdigitate to a remarkable degree in this area, and (as is to be expected) sometimes grade into one another. Firman (1971a, p. 57) provides the origin of the name of this formation and its type locality. He gives the distribution as from Merbein in Victoria to Berri in S. Australia. In a rapid reconnaissance of the Murray valley upstream, Chowilla Sand was noted at Monak in N.S.W. in sand quarries on the right bank of the Murray River and at Robinvale on the left bank, where the formation is partly silicified.

The lateral differentiation of the Chowilla Sand is illustrated by Fig. 33. At the windmill

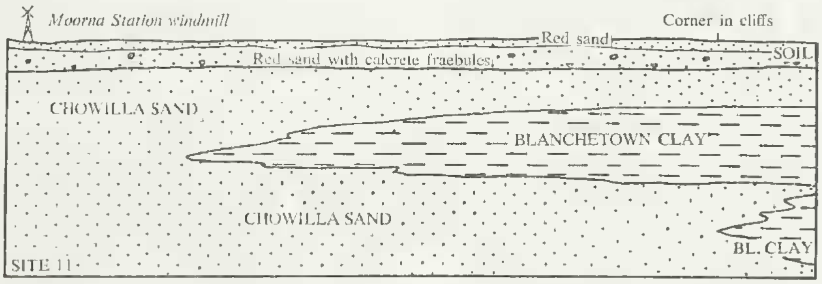


Fig. 33—Section of cliff N. of Moorna Station homestead, W. of Wentworth, N.S.W. Sketched from measured sections and cliff traverse to show lateral differentiation. Site 11. cf. Fig. 34.

end of the section are some bands of silcrete which the Aboriginals could have used for implements. At Moorna Station homestead extensive silcrete outcropped at river level before the building of locks raised the level of the water there, Mr. A. T. Honner informed me. The stone was used in the building of the homestead. At the corner marked on Fig. 33, N. of the homestead, the section was measured as follows:

0·5m Red sand
1·0m Same with calcrete nodules, white 5 YR 8/1 to pinkish white 8/2
5·3m Greenish olive gray 5 Y 5/2 Blanchetown Clay
5·4m Yellow Chowilla Sand to river level.

The Blanchetown Clay has shiny ped faces with fine selenite crystals, and oxidizes to light gray 5Y 7/1-6/1. In the middle is a narrow band of white 5Y 8/2 sand with some clay laminations. The top 5-10 cm is dark with pyrolusite, which is common as a secondary mineral in the sand formations. In the basal Chowilla Sand more pyrolusite occurs, and a piece of fossil bone was found. The bed should be prospected for vertebrate fossils. This is the same horizon as that in which occur the plentiful fossils at Bone Gulch.

Figure 34 provides a diagram of part of the Triple Swamp cliffs. It relates the important Bone Gulch (with nearby ostracod dolomite) to the Triple Swamp Gulch with its three dolomite bands. It also shows the extensive interpenetration of Chowilla Sand and Blanchetown Clay.

The two illustrations given of interpenetration, and the many sections with Chowilla Sand provided earlier in the paper, prove that this formation cannot be used as a *time indicator* but only as a *facies indicator*. In such conditions of lateral change it is difficult to correlate one section with another because of lack of datum planes. However, these are provided in the study area by pedoderms and fossils. Both of these require further study and refinement, but this will be discussed in the section on chronology. Another factor that can cause difficulty is the presence of disconformities and interformational erosion. The pedoderm is a disconformity in that a significant amount of time was involved in its formation. It represents a period of non-deposition. There are evidences of interformational erosion (e.g. Fig. 29) but these are on a minor scale, being usually small channels. They are therefore not very significant with respect to the stratigraphy. In the Paringi (N.S.W.) section two such channels occur in the top of the laterite. A minor one occurs in the top of the Chowilla Sand at Bone Gulch.

Although the Chowilla Sand dominates the section in some places (e.g. 33) it is absent or very reduced in others. Fig. 35 shows a section in a gulch running N. at the N. extremity of the Salt Creek cliffs in the Scrub Paddock of Kulcurna Station (originally called Hypurna, the Aboriginal name for the creek — J. Higgins).

(f) *Moorna Formation*

This is a new formation hereby proposed for an assortment of mostly unoxidized riverine deposits, gravels to silts, that occur below the Blanchetown Clay in the very broad and shallow Lake Victoria syncline. Because the Parilla Sand in this area is warped below river level, the only other formation occurring below the Blanchetown Clay is Chowilla Sand. This well-washed oxidized well-sorted channel deposit is readily distinguished. Unlike the

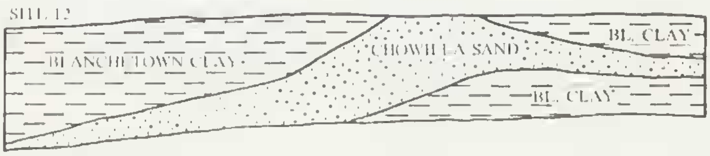


Fig. 34—Sketch of the cliff section between Bone Gulch and Dolomite Gulch (surveyed sections) to show interdigitation of Blanchetown Clay and Chowilla Sand. c. Fig. 33. For localities see Figs. 1, 4, 22 Site. 12.

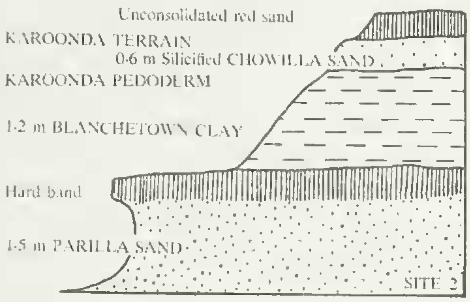


Fig. 35—Measured section of gulch in Scrub Paddock, Kulcurna Station, Cal Lal, N.S.W. Site 2.

Moorna Formation, it rises through the Blanchetown Clay, divides it, and caps it. The Moorna Formation always maintains its stratigraphic position.

The type section (Fig. 30) is on Moorna Station (from which it derives its name) at the W. end of Fishermans Cliff (Fig. 4, Site 13) so called by us because a fisherman has his hut at the E. end of the cliff. The paddock above is called The Selection by the Moorna management.

At the W. end of Fishermans Cliff (Fig. 30) the Moorna Formation consists of poorly-sorted gravel to coarse sand with the fragmentary bones of fish and marsupials, but at the E. end of the cliff (Fig. 31) it has laterally graded into laminated clayey silts and other fine deposits. The former is interpreted as a channel deposit, and the latter as a floodplain deposit. At the W. end the Chowilla Sand (with a fossil tortoise) is interposed between the Moorna Formation and the Blanchetown Clay. The Chowilla Sand is not quite typical because a lateral differentiation is beginning that becomes clear at the E. end of the cliff. For example, besides the usual well-sorted light brown sand there is some light gray (N7) with large reddish yellow (7·5 YR 6/6) mottles, and some is coarser than usual. Below is 4·6 m (and perhaps more) of Moorna Formation consisting of light gray to white (dolomitic) N7 to N8 coarse sand to gravel. It is clayey in some places and clean in others. A bore is desirable to determine the thickness of the deposit, and to discover if Parilla Sand lies below it. An undisturbed core through to the Bookpurnong Formation would be enlightening.

At the E. end of Fishermans Cliff (Fig. 31) the Chowilla Sand thins to 0·9 m, is clayey, and is greenish gray where unoxidized, i.e. it has graded into a sandy phase of the Blanchetown Clay, at least 7 m of which overlies it. A sharp break at the base appears to be a disconformity, and may be the Karoonda Terrain. The underlying Moorna Formation consists of consolidated sediments that form vertical cliffs at the section site. The top is 7·9 m from the top of the cliff.

The succession is:

Top 0·6m	Very pale brown sand 10 YR 7/3-4, some very hard (20 kg/sq cm) and some very soft (2 kg/sq cm)
0·6cm	White sand and pebbles of dolomite
9cm	Quartz sand with black pyrolusite The above two narrow bands have a local dip of 40° for 0·6m, which with the detrital dolomite is evidence of erosion. The eroded band is 28-60cm of white to very pale brown (10 YR 8/1-4) unstratified sand cemented in places with silcrete
3–4m	white sand to clayey sand; 76cm of this layer is finely laminated, 84 laminae being counted in 10 cm. Penetrometer measured 12-20 kg/sq cm
2·7 + m	Intercalated very pale brown sand (10 YR 7/4) and reddish brown (2·5 YR 5/4).

The Moorna Formation here is thus 16·3+ m thick. The thickest outcrop noted was at Merbein, where the left (W.) bank of the River Murray at the scenic lookout between the Winery and the Pumping Station reveals the section shown in Fig. 36. Here below mottled Blanchetown Clay up to 3·6 m thick is 4·3 m of Chowilla Sand. On the section line there is a conglomerate of masses of silcrete, quartz gravel and yellow sand lying on an uneven floor. Further S. towards the Pumping Station, a silcrete layer is in situ, and obviously this layer has provided the conglomerate. It is the Karoonda Terrain, and the silcrete is a pedoderm.

The Moorna Formation consists of over 17·9 m of off-white to light gray, very poorly-sorted, current-bedded sands to gravels with varying clay content, sparsely micaceous, pre-

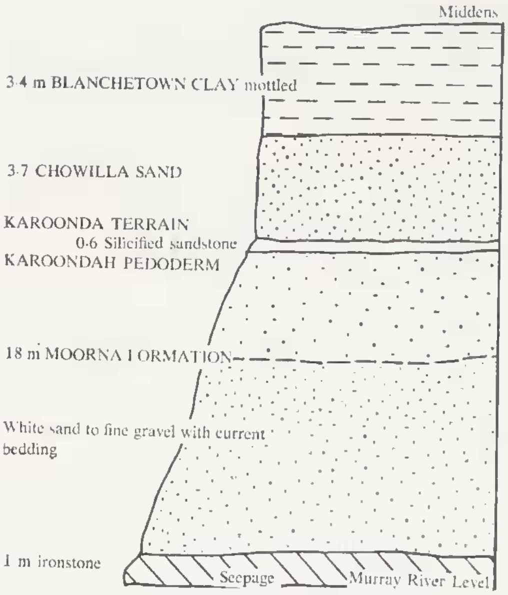


Fig. 36—Surveyed section of the cliff on the left bank (W.) of the Murray River at The Lookout, Merbein, Victoria.

dominantly clear quartz but some milky, with rounded to angular grains, cemented in places, rhizomorphs present in the upper 3 m, unoxidized. By contrast, at the base (at river level) is 0·6-1·8 m of soft ironstone through which water seeps to the river. The ferruginized sand is included in the Moorna Sand. What further thickness lies below is unknown. A bore to determine this and discover what formation lies below would be useful.

Referable to this formation are the strata below the Blanchetown Clay in the E. Moorna oxbow lake section (Fig. 6), of which the detail is as follows:

Top 51cm	Firm (20 kg/sq cm) red-brown (2·5 YR 4/4 and some lighter shades of clayey sand with pyrolusite
0·6cm	Light brown (7·5 Y 6/4) do. with detrital dolomite
18cm	As at top but more light brown in colour
0·6cm	Dolomite
20cm	As 18cm layer above
13cm	Stiff clayey sand. Same colour as above but with purplish bands. Gypsum rosettes 1.5-3cm diameter.

Thus the basic regional stratigraphy consists of Bookpurnong Formation (oldest) Loxton Sands, Parilla Sand, Blanchetown Clay, Chowilla Sand and Moorna Formation. For most of the study area only the last three outcrop. At this stage of geologic development, the Lake Bungunnia system became defunct as the Murray River cut down into this succession of strata, and drained them to base level.

The formations listed below as further regional deposits are thin surficial ones overlying the foregoing basal units. This is why the Blanchetown Clay forms the surface of much of the country and is widely used for excavation of tanks (water reservoirs).

(g) *Bakara Pedoderm* (Firman 1963, 1966, 1971a).

This is discussed in the accompanying paper on palaeopedology.

(h) *Woorinen Formation* (Lawrence 1966, Firman 1971a).

This comprises the E-W dune system described earlier (Figs. 9-10).

(i) *Loveday Pedoderm* (Firman 1966, 1967b).

This soil is developed on the Woorinen Formation dunes, and is discussed in the accompanying paper on palaeopedology.

(j) *Bunyip Sand* (Firman 1966, 1967b, 1971a).

This formation occurs as dunes, or as a veneer of red sand on the plateau in which the river tract is cut. About 0·8 km S. of Talgarry Station homestead is an example of a red sand dune belonging to this formation. It was eroded by winds during the 1967-8 drought so that its structure could be examined. The sections examined showed a homogeneous compacted red-brown sand. Aboriginal middens were associated with the dune, both on it and in it. The internal middens could be used to date the dunes.

On the hillslope above the Salt Creek measured section (Fig. 20) Bunyip Sand forms a deposit that is partly hillwash and partly aeolian. A section in a gulch showed:

Top 13cm	Loose red sand
10cm	Weak red (10 YR 5/4) sand forming a hardpan held by clay skins
36cm	Deeper red (10 R 4/3) sand

60cm Weak red sand lightened in colour by patches of earthy carbonate and nodules; also burrow fillings and in a few places thin seams down joint planes

60cm Mottled weak red (10 YR 4/6) and red (2·5 YR 5/6) and yellowish red (5 YR 5/6) with off-white patches of carbonate and white specks of gypsum. Latter mostly in lower half of this horizon. Also rough surface non-magnetic ironstone concretions up to 1·3 cm diameter

(k) *Yamba Formation* (Firman 1971a, Lawrence 1966).

Gypsiferous clays and sands in playas and low dunes. The gypsum is commonly of the "seed" and "flour" types. An example in the study area is the Morkalla district. Lawrence (1966) refers to a number of such areas.

3. *River Tract Formations*

The Murray River is incised deeply into the regional formations so that the present floodplain is about 37 m below the general terrain (Fig. 12). In the section on geomorphology, the tract in the area of study has been described as a pattern of higher red country and lower gray country (Fig. 5). These two types of country are surface expressions of two formations which will now be described, along with another formation proved by the Chowilla Dam site investigation, viz.:

Top (c) Coonambidgal Formation (Gray country)
(b) Monoman Formation (underlies c)
(a) Rufus Formation (Red country).

In addition to these riverine formations, there is the aeolian Lake Victoria Sand.

(a) *Rufus Formation*

This is a new formation here proposed and the type locality is the outlier shown on Fig. 5, where vertebrate fossils have been found that prove a Pleistocene age. The site is between the Wentworth-Renmark Road (at a bend in it) E. of Lake Victoria and N. of Frenchmans Creek on Dunedin Park Station, N.S.W. The name is after the nearby Rufus River which runs from Lake Victoria to the River Murray. The lithology is a clayey fine sand, and the facies riverine, as is shown by the nature of the sediments along with the flatness of the tops of the outliers. The latter were obviously once a continuous river terrace that was corraded and dissected. The outliers themselves have suffered some dissection—a mark of antiquity in this low rainfall area. The red terrace residuals stand up to about 7 m above the surrounding gray Coonambidgal sediments, and aprons of hillwash are common. The sandy fraction may be re-worked into local small dunes. The vegetation on this formation is *Eucalyptus largiflorens, Atriplex,* and such shrubs, then an under storey of herbs. The flora is renewed by floods. With it is associated a fauna of birds (including emu), marsupials, reptiles and invertebrates. Aboriginal middens, ovenstones and skeletons are found on the Rufus Formation residuals but none was found in the surrounding Coonambidgal floodplain. Three *Velesunio* middens were noted at the S. end of outlier 1. Middens also occur on the reworked red sands at the borders of some outliers. Small rounded polished pebbles occur, and these are thought to be emu gastroliths. The stratigraphy was tested by a surveyed section with auger holes.

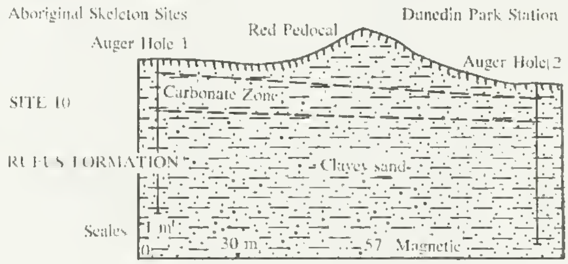


Fig. 37—Section in Rufus Formation residual marked 1 in Fig. 5. The site of Auger hole 2 was covered by the 1956 flood. It is at approximately the same level as Auger hole 1 (extreme left of figure) in Brown's Paddock, Keera Station, on the other side of the river (Fig. 38). Broken lines connect the limits of the carbonate zone proved in the two auger holes, but it is likely that the pedocal follows the present land surface. Site 10.

On the W. side of outlier 1, the section shown in Fig. 37 was determined, and the bore logs were:

Auger 1 72m E. of N-S. fence

0·20 m Red 2·5 YR 4/6 fine micaceous sand with very little clay (about 30cm of red sand has been eroded off this surface) grading to

0·33 m Red 2·5 YR 5/8 do. with masses of hard carbonate, grading to
0 41 m Very pale brown 10 YR 7/3 do. Gradual change to
0·86 m Light yellowish brown 2·5 Y 6/4 almost greenish fine sand. Sudden break to
0·08 m Light gray 5Y 7/2 fine sand. Decreasing amount of carbonate
0·28 m Yellowish brown 10 YR 5/8 fine sand without carbonate. Fairly sharp change to
0 58 m Light gray 5 Y 7/1 do. with yellowish brown mottles at the top
0·33+ m Same but darkened by pyrolusite. More clayey and some mottles. Plentiful mica at bottom.

3·07 m

Auger 2 On top of residual on clay pan where about 0·3m red sand has been stripped.
0·76m Red 2.5 YR 5/6 fine slightly clayey sand. Fine carbonate at surface and hard lumps from 25cm
0·36m Reddish yellow 5 YR 6/6 micaceous fine sand with little clay. Carbonate fraebules up to 4cm diameter, merging to
0·63m Lighter in colour and less carbonate. Very pale brown 10 YR 7/3 fine sand with fraebules to 2cm diameter but usually less. Marked change to
2·08m Brownish-yellow 10 YR 6/6 fine micaceous sand with little clay or carbonate. Lighter and darker bands present.

Auger 3 On slope at R.L. — 7·32m.
0·43m Red 10 R 4/6 moist fine sand merging to yellowish red 5 YR 5/6 merging to
0·18m Reddish yellow 7.5 YR 6/6
0·76m Pale brown 10 YR 6/3 fine sand with white masses of carbonate. At 0·81m from surface small translucent crystals of gypsum (selenite). At 1·22m from surface fraebules up to 1·3cm in diameter. Disappeared by 1·45m. Gradual change to
1·27m Light brownish gray 10 YR 6/2 clayey sand with small hard pieces of carbonate. Reduced to earthy patches at 1·5m and disappears at 1·8m. Merges z
0·79m Same with light gray mottles. Sandier at 2·85m
0·84m Light gray (2·5 Y 7/2 to 10 YR 7/2) slightly clayey sand with faint mottles of light yellowish brown 10 YR 6/4. At — 2·6m light bluish-gray mottles dominate and a layer of pyrolusite occurs. Rest of core to 4·27m light bluish-gray with 10 YR 6/4 and 7·5 YR 5/6 mottles. Water at 4·27m.

Auger 4 On floodplain of Coonambidgal sediments.
0·15m Strong brown 7·5 YR 5/6 slightly clayey fine sand
0·91m Brown to yellowish brown 10 YR 5/3 to 5/4 clayey micaceous fine sand. Gradual change to
0·41m Mottled pale brown 10 YR 6/3, brownish yellow 6/6, and light gray 7/1 micaceous fine sand. Marked change to
0·41m Mottled gray with decrease to disappearance of pale brown and large development of strong brown 7·5 YR 5/6 to dark brown 4/4. Increasing amount fo pyrolusite forming black patches. Sudden change to
0·20m Pale brown 10 YR 6/3 do. Water (salty but not strongly so) at 2·08m from surface
0·36m Clayey medium to coarse sand mottled pale brown and gray colours mostly 5 Y 6/1 and 5 GY 6/1. White carbonate forming hard lenticles. At 2·29m from surface oxidation colours gone
0·28m Pale brown sand for 15cm then layers of greenish gray colours 5 G 5/1 to 4/1. Some strong brown mottles at 2·7m. Water moderately salty.

In summary, the Rufus Formation consists here of fine micaceous sediments fully oxidized (red) at the surface, where by aeolian action sand has been sifted from clay. Only one thin lenticle (Auger 4) of coarser sediments was met. Below the surface brown colours dominate, below which the sediments are in a state of chemical reduction. Pedogenic carbonate follows the land surface so the erosion of this bank anyway took place in the Pleistocene. Perhaps heavier rainfall occurred then, and the geomorphology has remained much the same in succeeding drier times. It has been noted elsewhere, e.g. Brown's Paddock, Keera Station, Victoria (Fig. 38), that the carbonate soil on the Rufus Formation follows the present landform. The soil on the Rufus Formation consists of:

A1 0·30m Red micaceous fine sand
A2 0·20m Hardpan of red sand plus clay but without carbonate
B 1·8 m Brown sand with carbonate and some mottling
C 6+ m Mottled to gray sand.

The Coonambidgal sediments (represented by Bore 4 above) have no developed soil profile or accumulation of carbonate.

One outlier (Fig. 5) is horseshoe shaped, but is not a channel border dune. Its perimeter defines a Holocene meander, and indeed such permit the earlier vagaries of the river course to be worked out. The centre is not at floodplain level, but consists of a gradual slope.

In the NW. corner of Moorna Station, N.S.W. (air photo Lindsay Run 1, No. 5112) is outlier 7 (Fig. 5) which overlaps slightly into Dunedin Park Station. It is very irregular in shape and large, with a flat top. In Brown's Paddock on

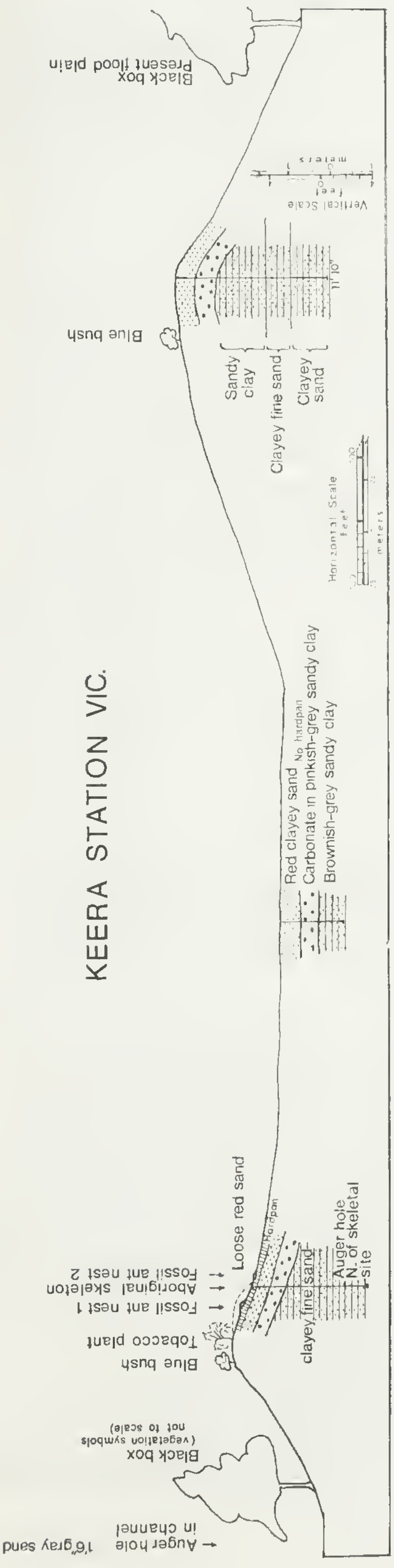


Fig. 38—Surveyed section of eroded Rufus Formation in Brown's Paddock, Keera Station, Victoria. The flat at the extreme left of the figure was covered by the 1956 flood (highest recorded flood).

Keera Station, Victoria, extensions of the Rufus Formation terrace form two dune-like ridges as shown in Fig. 38. The outcrops in this area show that the Pleistocene terrace represented by this formation was very wide, like the present one. On present evidence, the overall geometry of the river tract is not significantly different from what it was in the Middle Pleistocene (this term is purposely vague). The soil has mobilized calcite and selenite during its formation.

An outlier of Rufus Formation also forms an anchor for the S. end of the Lake Victoria lunette (Fig. 5). The sharp rather straight line defined by the S. limit of the lunette is a function of sand being blown past this outlier.

Finally, one of the most significant relics of this terrace is *within* the Lake Victoria basin, and *between* the lunette and the east wall of the basin. This has yielded a ramus of *Sarcophilus*, the Tasmanian Devil. The presence of Rufus Formation within the basin proves that the basin was cut before this formation was emplaced. Its presence so close to the wall of the basin suggests that the basin, like the rest of the river tract, has much the same morphology as it had in the Middle Pleistocene. These matters need more adequate investigation.

(b) *Monoman Formation*

The Murray River in the study area has scoured its tract to some depth, then infilled it again—a mark of changed conditions. At the Dam site (Fig. 4), over 390 river miles from the mouth, the Loxton Sands (Fig. 18) are incised to about 1·5 m below present sealevel, while at Swan Reach the down-cutting reaches about 15 m below sealevel (Firman 1971b, p. 3). The valley fill consists of two formations, the Monoman Formation being the lower and the Coonambidgal Formation the upper. The former was named by Firman (1971a and references) after Monoman Creek in the Dam area, and the D line of bores there is the type section (Fig. 39).

As there was danger of dam underflow through the coarse sediments of the Monoman Formation, a bitumenous grout curtain was designed to cut off water movement. A deep trial trench was dug for experimental purposes on

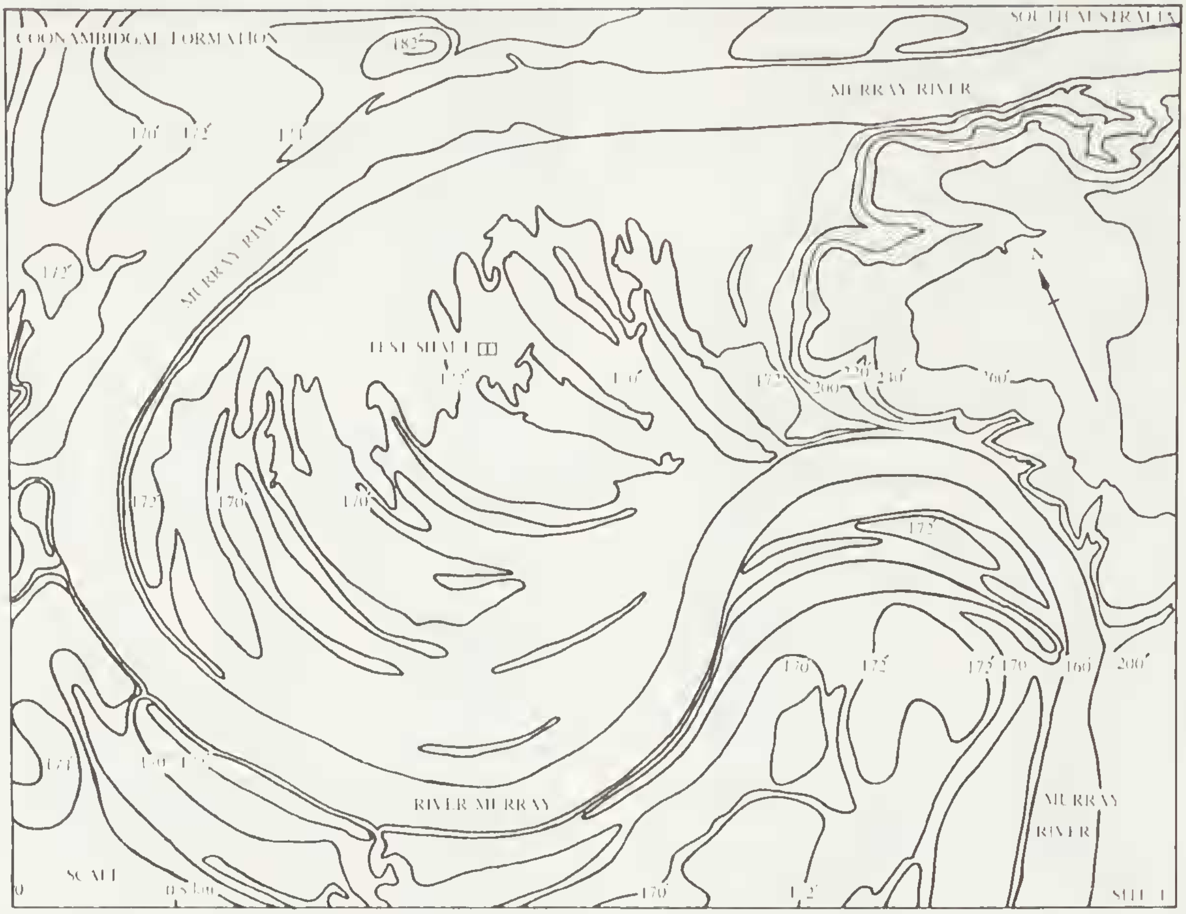


Fig. 39—Map of proposed Chowilla Dam area to show the extreme flatness of the present flood-plain, and the origin of the fossil finds (Fig. 40). Based on S.A. Engineering and Water Supply Chowilla Dam map, whose datum is 106·88 ft. below mean sealevel, Adelaide. The contours are in feet. Thus although the Murray River at the downstream end of this map is c. 390 miles (628 km) from the sea, it is only of the order of 53 ft. (16 m) above sealevel. Site 1.

the floodplain enclosed by the loop of the Murray River proper at Big Bend near the intersection of E.W.S. co-ordinates 99, 200 N and 60,050 E (approximately Lat. 140°25S, Long. 33° 59'S). The contractors placed samples of about 1 m³ of each of the sedimentary layers in a row, so that those involved with the setting of the grout curtain could devise suitable procedures. I examined these samples, and the depths given are approximations provided by the engineer, Mr. J. Kendricks:

0 –3 m Gray sandy clay of the present floodplain (unoxidized)
3 –4·5m Transitional, the percentage of clay reducing with depth, the coarseness of sediments increasing, and the oxidation status increasing
4·5–6 m Yellow, well washed, poorly sorted coarse sand to gravel (aquifer)
6 –7·5m Transitional, from oxidized to unoxidized
7·5–15 m Chemically reduced sediments, pH c.6.5.

Mr. Kendricks also advised that there is an horizon of logs and stumps across the valley at a level between 8·2 and 10·1 m below the surface. From the sample sediments I collected a small log and pieces of wood. Mr. H. D. Ingle of C.S.I.R.O. Wood Structure Section determined these as:

Eucalyptus largiflorens (log)
Eucalyptus camaldulensis?
Casuarina luehmannii?

These species are characteristic of the area at the present time. A piece of the log was dated by radiocarbon 7,200 ± 140 y B.P. (GaK-2513), while another piece of wood from the same fossil tree horizon dated 4,040 ± 100 y (Firman 1967b, 1971b). The latter is reported to come from "25 ft." below the surface, a rounded figure that probably means 7-8 m. However, it is clearly from the upper part of the wood horizon, so its younger age is to be expected. As these samples were wood, and adequate in size, their dates may be expected to be reliable. If so, and neglecting biologic age, a difference exists of 3,160 years, a considerable gap in Holocene chronology, and one associated round the world with a small climatic change. A disconformity is indicated, probably followed by rapid burial of the trees to preserve them. It is significant that in the D line of bores (Fig. 18) and the test trench, fossil wood was found only in this zone, and plentifully. This horizon may thus be taken for the present as the boundary between the Monoman Formation and the Coonambidgal Formation (Fig. 40). However, more precise data are still required.

The small fossil log grew fine, acicular, white to very pale green crystals of melanterite (determined by Dr. A. W. Beasley). They are

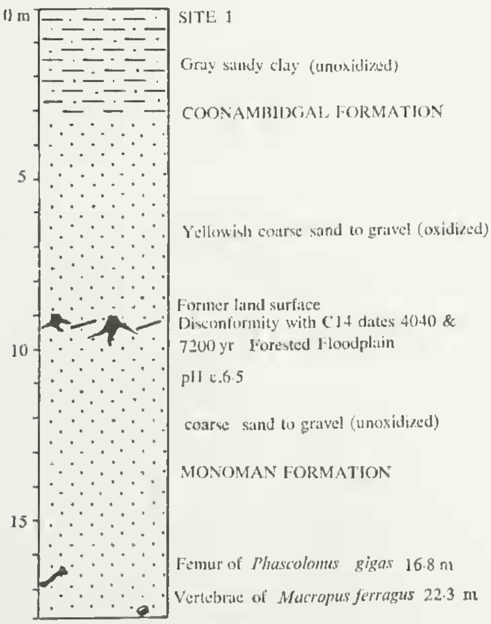


Fig. 40—Coonambidgal and Monoman Formations as revealed by the Test Shaft (Fig. 39) and cutoff trench, Chowilla Dam site, S.A. Site 1.

probably derived from the decomposition of marcasite. The environment was acid, as it to be expected where plant matter is decomposing, so the form of iron sulphide would be marcasite (Edwards and Baker 1951). After the scrapings were taken for identification, further crystals, grew on the same site, indicating continuing oxidation. Melanterite often occurs as an efflorescence on the walls and timbers of mines in the oxidized zone of pyritic ore bodies, especially in arid regions. Jarosite, also a product of the weathering of marcasite, was found infilling cavities, including cell spaces.

A black (chemically reduced) femur of *Phascolonus* cf. *gigas* (Marshall, this *Memoir*), the giant wombat, was found in the Monoman Formation at 16·8 m from the surface in the test trench, and a vertebra of *Macropus* cf. *ferragus* at 22·3 m in Bore Hole 20 on line D (Fig. 39). These fossils indicate a Pleistocene age, and thus support the idea of a disconformity at the fossil tree horizon. On the chronology suggested here, the Coonambidgal formation is Upper Holocene and the Monoman Formation Lower Holocene/Uppermost Pleistocene, with a Middle Holocene interval between. The Monoman Formation thus correlates at least in part with the Nulla Nulla Sand Member of the Lake Victoria Sand that constitutes the lunette on the E. side of Lake Victoria. The Monoman Formation is younger than the Rufus Formation, with a time interval between them during which that alluvium was dissected and deep channels corraded. This was no small interval, as a very large area (Fig. 4) was eroded and the incision was deep. As no suitable boring equipment was available, the distribution upstream of the Monoman Formation could not be determined.

The question remains as to why the Murray River corraded its course, then reversed this process and deposited the Monoman Formation. Corrasion is a function of rejuvenation. In spite of the Pinnaroo Block being a zone of tectonic uplift, the river there is cut below sealevel. This prompts a glacioeustatic interpretation, viz. that lowering of sealevel caused the corrasion. If the age given in this section to the Monoman Formation be correct, then the Last Glacial was the time when corrasion took place. However, it is not so easy to explain the infill. Rise of sealevel during the Flandrian Transgression could account for a new base-level but not infill to a considerable height above it. The river bank at the dam site is about 16 m above sealevel. Because S. Australia includes the Lake Eyre basin which is depressed below sealevel a datum of -100 ft from mean sealevel, Adelaide, was accepted, which has now been corrected to 106·88 ft. This figure has to be subtracted from the contours on Fig. 39. The alluvium rises to approximately 200 ft. at the dam site, which is about 28 m above present sealevel. Moreover, the Monoman Formation is a high energy deposit of well-washed sand and gravel, while the present floodplain consists of low energy clayey fine sand. Some factor other than eustasy is involved, and is probably a climatic one.

(c) *Coonambidgal Formation*

Both the Monoman and Coonambidgal Formations are variable riverine deposits best accommodated under the designation "Formation" rather than a rock term. Nevertheless, in the study area the latter has a sediment range offset to the fine side compared with the former. The Coonambidgal Formation overlies the Monoman Formation. The type section is the bank of Coonambidgal Creek, at the NE. corner of lot 75, Parish of Deniliquin North, N.S.W. (Butler 1958, Lawrence 1966, p. 548). This Formation has time equivalents (in part at least) on the general terrain above the river tract in the red Bunyip Sand (or redistributed such), the white Molineaux Sand, and the gypseous Yamba Formation. In the Lake Victoria basin its time equivalents are in the Talgarry Sand, the very recent Dunedin Park Sand, and the colluvial fans on the scarp forming the W. bank. However, all writers do not use this formational name in the same sense. Closer definition and dating is needed.

Before the Coonambidgal Formation was formally defined, Butler (1958) used the term to describe a "system" of riverine sediments. His section was adopted as the type one. There the sediments overlie the Mayrung Surface. At Moorna East Oxbow, Coonambidgal sediments overlie an old land surface (Fig. 7).

While the Coonambidgal sediments are flooded by the present river, they are not completely covered, showing that they are not completely in phase with the present river regime (cf. Dury 1960, 1965). Pels (1964b, p. 115) describes how the Murray follows the Coonambidgal sediments as far as Bullatale Creek offtake (W. of Tocumwal), "from whence it now travels parallel to them and a few miles S." Pels gives other examples of the partially ancestral character of the Coonambidgal Formation. Its age is Holocene. However, in the study area, all post-Blanchetown riverine sediments are confined to the present incised river tract. With the breakdown of the Pinnaroo Block barrage (or Padthaway Ridge) the Murray Gorge was incised. Upstream, in the slightly downflexed Lake Victoria region, the river swept to and fro, cutting the wide river valley that would make a Chowilla Dam inundation area so large (Fig. 4). This time of downcutting corresponds to some of the ancient stream deposition in the E. of the Murray Basin. The period is Post-Blanchetown Clay (Upper Pliocene?) and Pre-Rufus Formation (Middle? Pleistocene). This was a high energy activity, as also was the deposition of the early valley fill—the coarse sand and gravels of the Monoman Formation.

The typical surface expression of the Coonambidgal Formation in the Dam area is shown in Fig. 39. On Berribee Station (Fig. 4) there is a gentle slope to the river tract instead of the usual cliffs. The dunes of the Woorinen Formation are higher on the slope than the Coonambidgal riverine sediments, which occupy the bottom of the valley (Pls. 3-4). No interpenetration was found. The Coonambidgal sediments occupy a younger part of the river tract. This is in keeping with the radiocarbon datings. Carbonate in the surface soil of a Woorinen dune on Berribee Station dated 14,200 ± 790 y. (N.Z.) Fossil woods at the base of the Coonambidgal Formation (as interpreted in this paper) dated 4,040 and 7,200 y. respectively. On Berribee Station the Lindsay River forms an anabranch with the Murray River, and the enclosed land is called Lindsay Is. The collagen of Aboriginal bones from a burial in the top of a Coonambidgal channel border dune on Lindsay Island dated

3,580-± 370 y. (ANU-420D). Bowler (1967) dated Coonambidgal sediments as 5,110 ± 130 y. (N-302). A closer definition of the Coonambidgal Formation and more dates are required to define the period of riverine activity that its sediments represent.

(d) *Stratigraphic Correlation in Murray Basin*

The stratigraphy and geomorphology of the study area described above present a broad terrain consisting of Blanchetown Clay and associated deposits overlying marine beds. On this is a veneer of mostly windblown deposits. Due to the limited supply of suitable sediments, this veneer is relatively thin and in some places absent. Thus it is a common sight to see water reservoirs (tanks) cut in green Blanchetown Clay. Into this terrain the Murray River incised a deep tract, now partly infilled with the Monoman and Coonambidgal deposits. However, this W. side of the Murray Basin contrasts with the E. side. The latter has no marine beds in the stratigraphic succession, but a thick complex of mostly riverine deposits, often coarse, that contrast with the usually fine riverine sediments capped by the extensive lacustrine Blanchetown Clay with lenses of dolomite and dolomitic limestone found on the W. side of the Murray Basin. The terrain is a relict one (Pels 1966) and consists of the channel and floodplain deposits of ancestral and prior streams (Bowler 1967, Bowler and Harford 1963, 1966, Bowler and Macumber 1968, Dury 1963, Butler 1950, 1958, 1960, 1961, Langford-Smith 1960, 1962, Pels 1964a, b, 1966, Stannard 1962). Both tectonics and climatic change were master factors in the process. Earth movements of the Bass Strait Epoch began in the Mesozoic (Fig. 3) and faded in the lower Tertiary. Those of the Kosciusko Epoch began at the end of the Miocene and there are small displacements in Bookpurnong Beds in the Murray Basin, but the main uplift was in Upper Pliocene and Lower Pleistocene times. Tectonic movements caused diversion of streams over a long period (e.g. Pels 1966). The uplift of the Dividing Range resulted in two processes significant for the present study:

1. *The down-warping of the country* inland from the Divide (E. side, Murray Basin) so that riverine sediments 1500 km from the sea extend below sealevel.
2. *The construction of a massive bahada* or apron along the inner side of the range by the formation of numerous extensive coalescing fans.

It has not been evident before what became of these active prior and ancestral streams. The stratigraphy described shows that, following the retreat of the sea, they faded out in the W. into low energy streams, and into the series of lakes that deposited the Blanchetown Clay. With each phase of the downwarp, the rivers graded to a new base level.

On the Darling River NNE. of the study area, in the vicinity of Menindee, is a string of lakes that under natural conditions is dry except in flood time, but are now used for water storage. Connecting these lakes is a gypsiferous greenish gray clay that I think should be referred to the Blanchetown Clay. Thus in this area also there are extensive fine lacustrine sediments forming part of the lake system or systems into which the ancient streams flowed from probably the

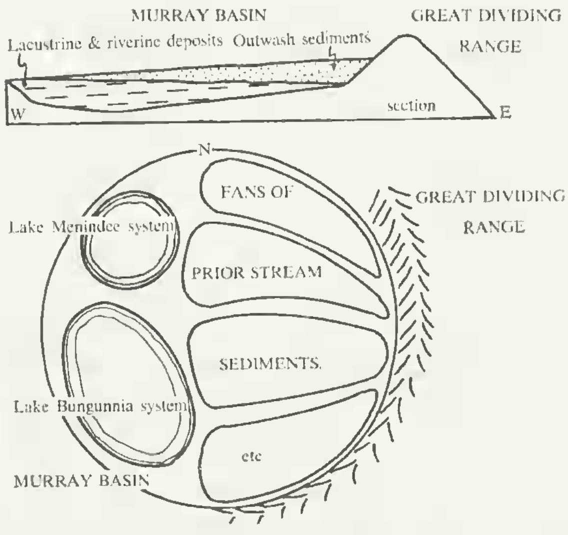


Fig. 41—Notional diagram (in section and plan) of the relationships in the Murray Basin of the depositional fans along the foot of the Dividing Range to the fine lake/river sediments described in this *Memoir*. The Lake Menindee and Lake Bungunnia systems are separated because of their significantly different levels at the present time, but the matter has not been investigated.

Upper Pliocene to the Lower Pleistocene (see section on Chronology). Significantly, this was the period of active tectonic movements when the Pinnaroo Block was uplifted and extensive damming of the Murray occurred. Figure 41 is a schematic representation of the concept outlined above.

(c) *Lake Victoria Sand*

This stratigraphic name is hereby proposed for the large and complex lunette (in the original sense of Hills 1940 for a crescentic dune) on the E. side of Lake Victoria. It is composed of three members:

3. Dunedin Park Sand. Mostly 0-200 yr
2. Talgarry Sand. Upper Holocene
1. Nulla Nulla Sand. Upper Pleistocene to Lower Holocene.

The Lake Victoria Sand is named after the lake it borders, while the three members are named after the three pastoral stations that include areas of the lunette on their properties.

The low dynamics of this flatland river system have already been discussed. A result is that even the dune sands are finer than is normal, as can be seen in the section on grain size analyses. Another unusual feature of the lunette is the comparative rarity of normal dune structures due to sandfalls. The majority of the bedding is subhorizontal (Pl. 10, fig. 1). The inference is that the wind dynamics exceeded the sand supply, so that the dunes during building were in a more or less constant state of blowout. The smaller grain size of the sand meant that it was lighter and could more easily be blown.

The lunette is a large structure 15 km long and up to 2 km wide, though more usually 0·4-0·8 km in width. It thins out at each end, but the two members thin out differentially. The Nulla Nulla Sand thins earlier towards the S. end, while the Talgarry thins out earlier towards the N. This structure could be due to small differences in prevailing winds at the time of construction (considered more likely) and/or differences in the river regime supplying the sand. The S. end of the lunette is tied to an outlier of Rufus Formation. The lake side of the lunette is characterized by a frill of gulches and interfluves (Fig. 16) while the inland side is notable for its numerous sandfalls of Dunedin Park Sand. The crest of the lunette is commonly blown out leaving mesa-shaped residuals of Talgarry Sand, with its characteristic gray columnar soil (Pl. 10, fig. 1). The floor of a blowout is usually a subhorizontal paleosol. The result is a long flat blowout across the lunette with a sandfall at the inland end. Along the lower part of the lake slopes there is a sand apron (14° steepest slope where measured), compounded of sand blown up from the beach by W. winds, and fans of sand washed out of the

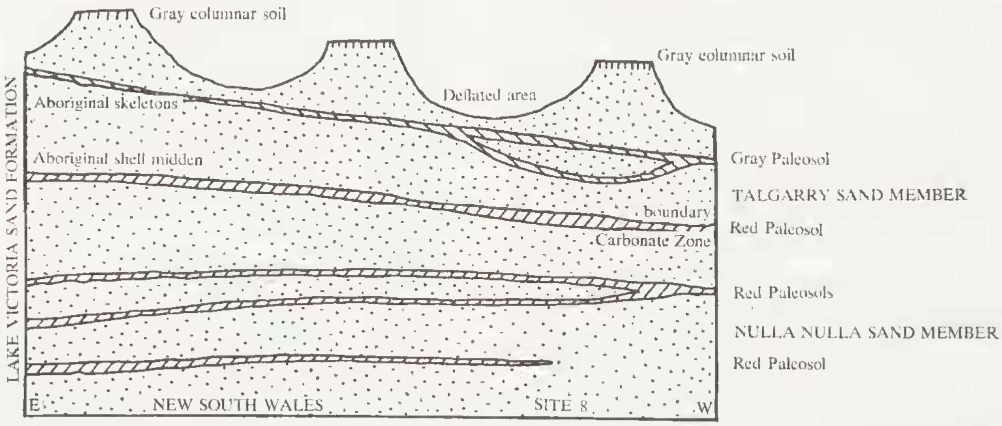


Fig. 42—Sketch of S. wall of Gulch N12 (Fig. 16), in the lunette on the E. side of Lake Victoria, as revealed by drought conditions in 1968. This is the largest number of superposed paleosol units seen in the lunette. The basic occurrence is shown in Fig. 4 of Gill on Palaeopedology, this *Memoir*. Site 8

gulches by the infrequent rains. The apron is included in the Dunedin Park Sand.

In 1967-8 during a drought, the stratigraphy of the lunette was revealed by wind erosion and absence of vegetation. Difficulty was experienced in distinguishing the numerous gulches, so those N. of the Nulla/Talgarry fence have been numbered northwards using the prefix N., while those S. of the fence have been given the prefix S. (Fig. 16). Interfluves are given thus N1/2. All the gulches N. of the fence and many of these S. of it were marked at their heads by long pegs with numbers drilled into the wood, as paint would be sand-blasted away. In addition, four deeply-sunk concrete bench marks were inserted in the area of most intense study. These are linked to the Chowilla Dam survey (and so sealevel at Adelaide), as follows:

BM 1	47 m	above	MSL	Adelaide
BM 2	43 m	"	"	"
BM 3	49 m	"	"	"
BM 4	47 m	"	"	"

The foregoing system makes it possible to locate a site with accuracy, and give its R.L. Because of the subhorizontal structure of the lunette, such an R.L. is more significant than in most dune systems.

Fig. 42 is a sketch of the N. wall of the interfluve N14/15. This section shows clearly the two main Members—Nulla and Talgarry. The distinction is not always so obvious, because in such an environment there is always some sand movement and remodelling complicating the stratigraphy. Overall, the two Members are readily distinguished, and are important in that they represent two periods of dune building. The paleosols represented in Fig. 42 constitute the largest number seen in one section. Such paleosols reflect the general alternation of stable and unstable conditions seen in the in the E-W. dunes. By means of radiocarbon dating it would be possible to make correlations within the range of the method. The few assays it was possible to make are given in the section on chronology, where the possibilities of such an investigation can be glimpsed.

The two Members making up the bulk of the lunette can be distinguished as follows:

Nulla Nulla Sand	*Talgarry Sand*
1. More compact (3-5 kg/cm^2)	Less compact (1-3 kg/cm^2)
2. More leached	Less leached
Free carbonate rare (unless transferred from above)	Free carbonate common
	Rhizomorphs present
Selenite needles rare	Selenite needles common
3. Red non-columnar paleosols	Gray columnar paleosols
4. Internal structures reduced	Internal structures fresh
5. Extinct marsupials	Extant marsupials
6. Human remains only in top	Human remains throughout
7. Fossil bones mineralized (may be coated with carbonate)	Fossil bones not mineralized (or much less than those in the Nulla Sand)
8. Clay more organized as skins	Clay mostly free.

There is much variation, the usual difficulties of dune stratigraphy being present. However, the differences are real. A check with a Munsell chart showed that, although occasionally the

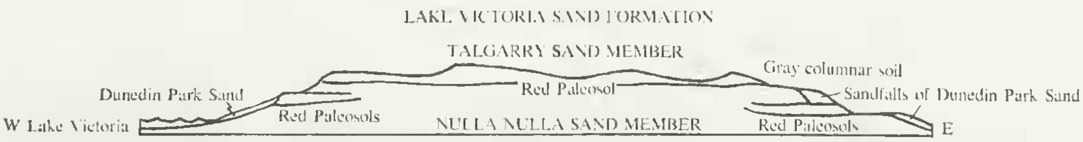


Fig. 43—Diagrammatic E-W. section of the Lake Victoria lunette to show the subhorizontal nature of its essential structures. The summit of the lunette is wind-eroded, resulting in the Dunedin Park sandfalls to the E. The hamada of Dunedin Park sand on the lake frontage is partly blown up from the beach and partly washed down from the gulches. The prevailing wind is W.

lowest Talgarry soil becomes reddish, it does not become as red as the Nulla Nulla paleosols. The fossils are an important difference.

During the depositional break between the two members, blowout structures developed. In places the paleosols of the Nulla Nulla Sand are truncated on the W. face of the lunette (Fig. 43). In NS. section deep gulches are seen in the Nulla Nulla Sand that have been infilled with Talgarry Sand (e.g. N14).

The erosion of the red paleosol in the fossil swale is part of the evidence of this process. No such corrasion has been noted during the emplacement of the Nulla Sand. Thus, in the late Pleistocene, when the giant marsupials were becoming extinct, deposition gradually ceased on the Lake Victoria lunette. The time of maximal world glaciation of c.18,000 yr B.P. is significant for terrace building and regional (E.-W.) dune building, so perhaps it was also for this lunette in the river tract.

Because of the erosion between the two members of the Lake Victoria Sand, the top of the Nulla Sand has different ages in different sites, e.g.:

1. Mussel shells from midden in red paleosol a short distance N. of the Nulla/Talgarry fence where the Nulla Sand is uneroded, 6,360 ± 140 yr B.P.
2. Mussel shells from midden near peg N18 at head of gulch 5·3 m below top of Nulla Sand, 15,900 ± 275 yr B.P.
3. Mussel shells in Nulla Sand at N. end of lunette 1·2 km SE. of Old Hotel site, Nulla Station, 16,720 ± 260 yr B.P. Charcoal from this midden 15,300 ± 500 yr B.P.
4. Mussel shells from midden in red paleosol in second last gulch at S. end of lunette, Talgarry Station (Fig. 44), 17,530 ± 320 yr B.P.

Corrasion tends to stop at a paleosol because such are much more difficult to erode. The foregoing evidence suggests that the erosion interval was mid-Holocene, the same time as the interval between the Monoman and Coonambidgal Formations. However, more work on the stratigraphy and many more dates are required to establish this. On Moorna Station, on the high ground above Triple Swamp at Triple Swamp Gulch (Pl. 9), an Aboriginal midden was found on the B horizon of the soil where the original A had been eroded (apparently by deflation) and then reconstituted. The mussel shells from between the original B and the re-built A horizon dated 7210 ± 160 yr B.P. This stripping could therefore belong to the same period.

Thus, on present evidence, the Nulla Sand was built up mostly in the late Pleistocene. The included paleosols dated by the middens in them (14,000-17,000 yr) appear to tie up with the paleosols of that range of C14 dates in the E-W. dunes on Berribee Station, at Ouyen and at Swan Hill, even with soil formation in S. Victoria (see section in chronology).

A lakeside profile was surveyed (Fig. 45) when the lake level was at its lowest during the drought. A wide beach of white sand was exposed, and such is the source for sand blown up the profile by the prevailing W. winds.

One may well ask what becomes of all the clay transported by the river with this sand. Much clay has accumulated on the floor of Lake Victoria. The Darling River is muddier

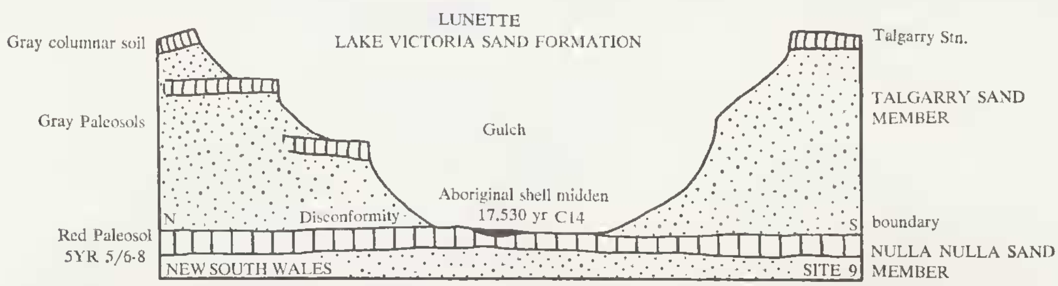


Fig. 44—Section of second last gulch at the S. end of the Lake Victoria lunette (Fig. 16). Site 9.

than the Murray because its waters are fresher. As the percentage of dissolved salts increases (especially sodium), as in the Murray River, the clay flocculates. Much is deposited in the low energy anabranches and billabongs or oxbows (e.g. Fig. 7). Such a stream does not penetrate the ground easily or erode its banks by wetting and weakening. Erosion is by physical processes. Much clay is blown up into the lunette as aggregates or attached to sand grains. In swales and such low areas, strong wetting can re-organize the clay as clay skins that bring about the compaction of the sand. The fineness of the sand and the evenness of grain size makes this process the more effective. Numerous fossil claypans of this type can be seen in the Nulla Sand but they are rare in the Talgarry Sand. They erode with a typical fine herringbone pattern. Sections of such pans can be seen in the walls of gulches.

River and wind action have thus combined to reduce clay content and build a stockpile of fine sand over many millenia. This lunette sandpile has been roughly estimated at 100,000,000 tonnes. It has provided a habitat for marsupials, placentals, reptiles, birds and man. This biologic history has been preserved because of the readiness with which the dead animals were interred in the rather dry sands. However, the river system is no longer adequate to transport sand to this site, but the wind energy is adequate (with the aid of introduced animals) to erode the dunes, revealing their inner structure and fossil content (Marshall, this *Memoir*).

(f) *Lake Victoria Hamada*

No formational name has been created for the colluvial fans that overlie the Blanchetown Clay and associated formations that constitute the scarp along the W. side of Lake Victoria. To a certain extent they are the time equivalents of the Lake Victoria Sand. The youngest member is a series of recent fans that are obviously the latest product of sediment flow on these slopes. The fans are geomorphologically complete except for contemporary gullying. Although so young, the fans have a surface held by carbonate precipitation, usually within the range of 5-15 cm deep. This carthy carbonate has preserved Aboriginal skeletons and middens. In the field we called it the "indurated layer", and it can be traced across all the erosion amphitheatres (Fig. 14) on the W. side of the lake. It continues right up to the edge of the general terrain some 35 m above the lake. The hamada slope is of the order of 10°.

About 400 m N. of a windmill and J. May's camp (shown in Fig. 17) on Noola Station is a typical fan which includes Aboriginal middens. Associated with one of these were carbonized twigs that looked like salt bush. A radiocarbon assay gave a "modern" age (ANU-423), which is less than 200 years. As the midden was immediately below and affected by the indurated layer, this accumulation of carbonate is very recent, and the gullying even more recent, i.e. during European occupation. The widespread occurrence of the indurated layer shows that the hamada had achieved a certain degree of stability. Figure 46 shows a

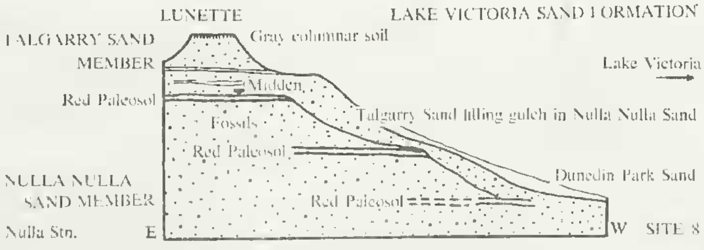


Fig. 45—Sketch of an actual lakeside profile in the Lake Victoria lunette, Nulla Station, N.S.W. Site 8. Boundaries between the Nulla Nulla Sand and Talgarry Sand are subhorizontal normal to the lake, but parallel to the lake are scalloped in places by fossil gulches. The structures reveal successive phases of stability of the terrain.

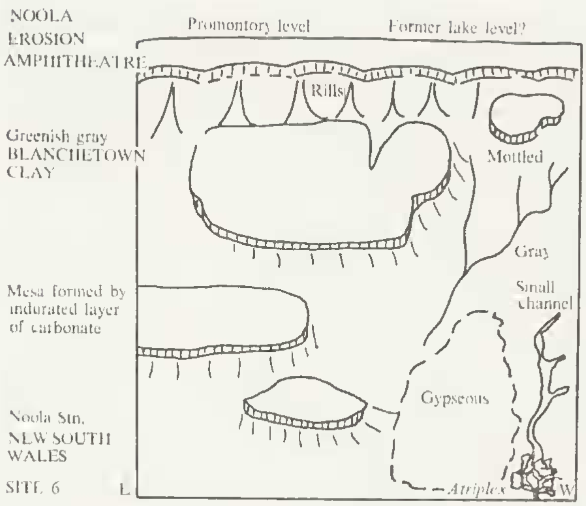


Fig. 46—Sketch of slope in Noola Erosion Amphitheatre showing the latest pedocal, consisting of indurated layer 10-15 cm thick, which covers the low fan slopes (c. 10°) at the foot of the scarp forming the W. shore of Lake Victoria, N.S.W. Carbonized twigs from this layer dated 'modern' by C14, so the soil is less than 200 yr old. The strong dissection has therefore occurred since European occupation. Aboriginal bones and middens are cemented in this layer.

typical dissection of the indurated layer on the N. side of the promontory constituting the S. limit of the Noola erosion amphitheatre (Fig. 14). This layer is part of a 1·5 m oxidized zone on the promontory surface (0°-3°), below which is a similar thickness of mottling in the Blanchetown Clay. On the 10° slope from this promontory is 15-25 cm of indurated layer resting directly on 1·5 m of mottled Blanchetown Clay. In the middle of the Lake Victoria amphitheatre the oxidized zone attains a thickness of 4·5 m.

The development of a hamada that was later dissected is a process that has occurred a number of times on this lake scarp. It is part of the impermanence of semi-arid terrains. Figure 47 shows a fossil gulch which contained bettong bones. The bones were strewn out in a manner such as occurs in hillwash, so the animal was not burrowing, but has the same age as the sediments.

A gulch 1·1 m deep near the N. wall of the Lake Victoria amphitheatre, about 100 m W. of a mesa reveals a Pleistocene gulch fill of light brown (7·5 YR 6/4) clayey sand to brown (5/4) sandy clay with small lenticles of gravel (Fig. 48). A zone of earthy carbonate 25-40 cm deep occupies the surface of the fill.

A small Aboriginal midden and fireplace of oval section was present 45 cm from the surface. It consisted of well compacted (8-10 kg/cm^2) ash, charcoal and mussel shells 20 cm deep and 45 cm wide. The general colour was brown (7·5 YR 4/2 to dark brown (3/2). The bottom of the structure was lined with charcoal suggesting an excavated fireplace. Many of the mussel shells were on edge, standing vertically. Four worm burrows were visible in vertical section and two in horizontal section. None could be found in the surrounding sediments. This is taken to mean that a zone of high organic content attracted the worms. A radiocarbon dating of the charcoal gave 18,200 ± 800 yr B.P. This is the oldest Aboriginal site dated by us in the project area.

Chronology

"The same regions do not remain always sea or always land, but all change their condition in the course of time". —Aristotle (384-322 B.C.)

1. *Methods*

The chronology of the formations described is difficult because no materials suitable for isotopic assay older than the range of radiocarbon have been found. Moreover, the formations exposed in natural sections of the country rock over most of the area are Moorna Forma-

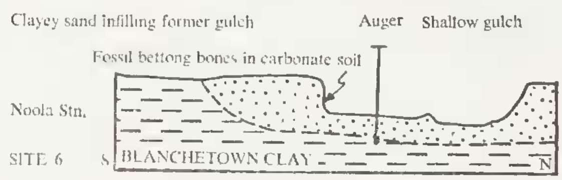


Fig. 47—Measured section of gulch (10·4 m wide, 1·2 m deep) in hamada on W. shore of Lake Victoria, cut in the fill of a still older gulch. The S. bank shows 38 cm of brown 7·5YR 5/4 clayey sand over an earthy carbonate zone (B horizon) 69 cm thick. Nearby this zone was dated 18,200 yr (GaK-2514) on the charcoal of an Aboriginal midden. In the above section bettong bones were taken from the carbonate cement.

tion, Blanchetown Clay and Chowilla Sand. These sediments suffer lateral differentiation and considerable interdigitation, thus complicating correlation. The chronology is therefore based on certain datum planes that traverse the area, as follows:

5. Chronometric dating by radiocarbon.
4. Paleosol that mobilized carbonates (calcrete) and beyond the range of C14 (earliest pedocal).
3. Paleosol that mobilized silica (silcrete, common opal, disperse silica giving silicified sands).
2. Paleosol that mobilized non-magnetic iron oxide (laterite).
1. Bed with Cheltenhamian marine fossils, met in oil bores and in the Tareena water well (Tate 1899).

These stratigraphic planes can be demonstrated to be superposed.

The paleosols provide datum planes that are independent of the lateral differentiation and interdigitation. They also define successive changes of climate and related geochemical conditions. This palaeoclimatic sequence can be paralleled elsewhere, which assists extrapolation. Further, Marshall (this Memoir) has identified in the Moorna Formation vertebrate taxa comparable with those found in Pliocene beds elsewhere. This formation lies below and is older than the Blanchetown Clay and Chowilla Sand. In the valley of the Murray River an oxidized fluviatile terrace (Rufus Formation) contains a vertebrate fauna with taxa such as occur in Pleistocene deposits elsewhere. Vertebrates also assist with the chronology of the lunette on the E. side of Lake Victoria, where the lower part of the formation contains large extinct marsupials, while the higher part contains only extant taxa.

An attempt was made to use palynology, even though it has a restricted application in this dry, oxidized terrain. Two horizons of dark gray to black fine sediments were found, one at the top of the Parilla Sand in the Murray River cliffs beside Kulcurna Homestead, and another nearby at the S. end of Salt Creek in the Blanchetown Clay where it thins out on an old lake shore. The former provided no definitive evidence, but the latter gave a flora more or less identical with that of the present semi-arid terrain (Churchill, this Memoir). There is thus no chronologic value in the results, but they are of profound ecologic interest in that there is an indication of the time of incoming of the present aridity following the subtropical rainforest milieu evidenced by the laterite. This aspect is dealt with in the section on palaeoclimatology. Every method that appeared likely to assist the chronology was attempted, including fission track dating of opal, palaeomagnetism, thermoluminescence, neutron activation, the U/Th assay of pedogenic calcretes, and fluorine/phosphate analyses of bones. Reports on the application of some of these methods are given in accompanying papers. By synthesizing the results of the datum plane study and the above methods with the tectonic and palaeoclimatic patterns, a chronology has been derived which is about as far as one can go under present circumstances.

2. *Tectonic Pattern*

In the S. Australian River Murray region the late Cainozoic stratification is regular, and consistent over a great area. The sequence is:

Youngest	Bungunnia Limestone
	Blanchetown Clay
	Chowilla Sand
Oldest	Parilla Sand.

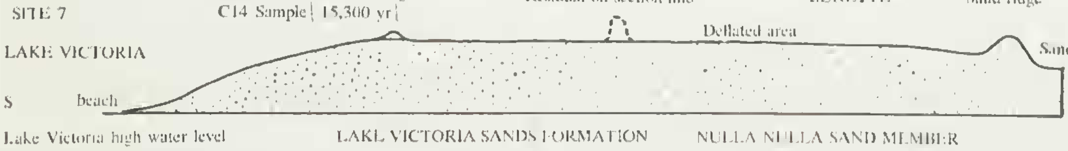


Fig. 48—Surveyed section 292 m long on the N. shore of Lake Victoria E. of the Old Hotel site at end of track from Nulla Station.

As can be seen by Fig. 18, the Parilla Sand outcrops strongly at the dam site in the valley walls. This is true also as far east as Kulcurna Homestead. The formation is then affected by the Lake Victoria Syncline and disappears from sight in the river banks, not to re-appear again till Paringi 29 km SE. of Mildura. About 1·5 km SE. of the Paringi turnoff the Murray River cliffs come close to the Robinvale-Gol Gol road (Sturt Highway). There cliffs about 25 m high show 4·5 m of Parilla Sand which, unlike any other formation present, develops a vertical face. The distance between these two outcrops of Parilla Sand is about 130 km in a direct line. The Parilla Sand is a gray fluviatile clayey sand of constant character, apparently not affected by significant tectonic movements during its emplacement. It has since been flexed downwards in the Lake Victoria Syncline. By contrast, the succeeding formations have been affected by tectonic movements. The Moorna Formation, interposed between the Parilla Sand and overlying formations, is limited (as far as we know) to the Lake Victoria Syncline. Above the Moorna Formation is the Blanchetown Clay/Chowilla Sand complex. In S. Australia (on the uplift block) these formations hold a definite order, but in the depressed Lake Victoria Syncline area, they grossly interdigitate and the Blanchetown Clay reaches a much greater thickness (Pl. 5). The onset of significant Kosciusko Epoch earth movements can thus be recognized in the study area. The Murray Basin is so large a structure, that to fit its earth movements into a tectonic pattern, one needs to view the tectonics of the whole of SE. Australia and not movements on local faults as at Melbourne and Adelaide. This general view shows a mid-Tertiary quiescence with slight movements at the end of the Miocene and in the Lower Pliocene, then strong movements in the Upper Pliocene and Lower Pleistocene. Since the movements in the Lake Victoria Syncline are so subdued (deep movements are buffered by 1·5-3 km of soft sediments—Fig. 3), it is reasonable to conclude that the well-marked changes following the deposition of the Parilla Sand are those of the Upper Pliocene. If this be so, then the Moorna Formation represents the beginning of the damming of the Murray River by the uplift of the Pinnaroo Block, while the lacustrine deposits of the Blanchetown Clay (and associated limestone lenses) mark the establishment of this impedance to drainage. It would seem that this was variable, because after some lacustrine deposits were emplaced, the lake dried up so as to yield dolomite then pedogenic opal (Fig. 26) and silcrete. The oscillation between channel, floodplain and lacustrine facies, as reflected in the interdigitation of the Chowilla Sand/Blanchetown Clay sediments, bears witness to these changing conditions.

This argument from tectonic pattern makes the Moorna Formation Upper Pliocene (a conclusion reached by Marshall in this volume on the evidence of vertebrate fossils) and the Blanchetown Clay/Chowilla Sand complex Upper Pliocene to Lower Pleistocene, if we can define what that means. This will be attempted in the next section which deals with the Plio-Pleistocene boundary. Fig. 3 shows post-Eocene sedimentation to have been regular until post-Bookpurnong times, after which an appreciable thickening of sediments occurred in the Lake Victoria region. The Bookpurnong Beds are uppermost Miocene in the study area as judged by the fauna from the Tareena well, already discussed. However, it should be noted that this formation over its very wide distribution is somewhat diachronous (Lawrence 1966, p. 534), apparently due to the slow retreat of the sea in the Murray Basin from E. to W. The argument from the tectonic pattern is thus consistent with the other methods of dating.

3. *Plio-Pleistocene Boundary*

Discussions about which beds are Pliocene and which Pleistocene have little meaning under present circumstances, unless one states what is accepted as the boundary. Shotton (1967) and others have pointed out that various interpretations of the boundary fall between 1·75 and 3·5 m.y. A review of the Plio-Pleistocene boundary in Australia has recently been made (Gill 1972b).

In 1948, INQUA defined this boundary by unanimous vote, so the procedural position is unequivocal. The chronometric dating and extrapolation of this horizon is the problem. In the writer's opinion, the best approximation on present evidence is the dating of the boundary at about 1·8 m.y. This is used temporarily in order to make objective what is meant in this paper by the terms Pliocene and Pleistocene.

In the section on palaeoclimatology the changes in climate are described. These have general chronologic significance, as also do the changes in flora that accompanied them. Important changes in fauna also occurred, but these have yet to be elucidated before they can be used for definitive dating. Changes in soil type also accompanied changes in climate, and these are described in the accompanying paper on palaeopedology.

4. *Radiocarbon Dating*

The following dates were obtained from assays of materials from the study area:

1. **Modern (ANU-423).** Wood charcoal from small shoots in surficial layer indurated with secondary carbonate. Associated with an Aboriginal midden of mussel shells *(Velesunio ambiguus).* The site is on a fan forming part of the hamada on the NW. side of Lake Victoria, about 0.4 km N. of J. May's camp near the lake windmill on Noola Station, N.S.W., Anabranch Military map ref. 422,800. The result dates Aboriginal occupation of the site, provides a maximal date for the latest lithification by secondary carbonate, and proves the modern age of the widespread gullying that cuts the indurated layer.
2. **180 ± 80 yr B.P. (GaK-2511).** Charcoal from midden of *Velesunio* shells on the N. side of the polythene water pipeline from near the Talgarry Station homestead to Lake Victoria, N.S.W. The site is on high ground (near top of ridge with *Casuarina* copse) overlooking the salt lake behind the lunette (Field sample CHA/253). Dates Aboriginal occupation, and in a general way the uncompacted sandy soil in which it occurred.
3. **770 ± 150 yr B.P. (GaK-3217).** Finely disseminated carbon from core taken in floor of Moorna East oxbow (billabong) below soft loose sediments and overlying a highly compact mottled zone (B horizon of paleosol) of pre-oxbow land surface. Collected 23 May 1969. Recovered carbon only 0·7 gm so the date could contain an unexpected error. However, the date is in keeping with the recent age of the oxbow inferred from sharp banks and low talus slopes. Moorna Station, W. of Wentworth, N.S.W.
4. **1320 ± 80 yr B.P. (GaK-2008).** Charcoal from large Aboriginal midden of *Velesunio* shells beside a prominent track S. of the pipeline on Talgarry Station on a low dune associated with the inland limit of the lunette complex, W. of the salt lake and fenceline. Collected 22 April 1968. Illustrated in Gill 1969, p. 177, fig. 2.
5. **1660 ± 110 yr B.P. (Gak-2512).** Charcoal from Aboriginal midden on the S. side of the pipeline track mentioned under (2) but E. of *Casuarina* copse at top of slope, Talgarry Station, N.S.W. In uncompacted sandy soil, SW. of dam (at gate in fence).
6. **1930 ± 80 yr B.P. (GaK-2007).** Charcoal from Aboriginal oven with calcrete ovenstones in sand on top of hill near Salt Creek SE. of Dickie's Gate beside copse of trees in NE. corner of Scrub Paddock, Kulcurna Station, N.S.W. Collected 28 April 1968.
7. **3580 ± 370 yr B.P. (ANU-420D).** Collagen of Aboriginal bones from burial in top of channel border dune, Lindsay Island, Berribee Station (Fig. 5), Victoria. Sample CHA/174, site 2.
8. **4170 ± 200 yr B.P. (GaK-1432).** Collagen of Aboriginal bones (extended burial) from Site 16, Lybra Paddock, Keera Station. W. of Merbein, Victoria (Mildura Military Map ref. 481,779). In SE. Australia collagen is leached away after 5-6,000 yr so that bone datings are seldom possible on this fraction if beyond that age. The four samples from this site (GaK-1430-3) are intrusive burials, and although reasonably sized samples were provided the yield was sub-standard. As a result GaK-1431 was measured under low gas pressure and 1432-3 were diluted with dead carbon. The dates may therefore not be accurate, but it is noted that where two skeletons occurred one above the other, the ages are in the correct order, viz. 4170 and 4400 yr.
9. **4400 ± 220 yr B.P. (GaK-1433).** Same type of material and same site as foregoing sample. Extended burial.
10. **5350 ± 290 yr B.P. (GaK-1431).** Ditto. Flexed burial.
11. **5840 ± 90 yr B.P. (GaK-1429).** Charcoal closely associated with loosely flexed Aboriginal skeleton, Brown's Paddock (Fig. 38), Keera Station, Victoria. Mildura Military Map ref. 469,777.
12. **5900 ± 550 yr B.P. (GaK-1430).** Collagen of Aboriginal bones from Site 5, Lybra Paddock, Keera Station, Victoria. This was a sitting burial. The samples from Keera Station were selected to cover various types of burial.
13. **6360 ± 140 yr B.P. (GaK-2416).** *Velesunio* shells from Aboriginal midden in red paleosol between the Nulla Nulla Sand and Talgarry Sand (members of the Lake Victoria Sand formation) where no inter-Member erosion has occurred. This is therefore a minimial date for the Nulla Nulla Sand. Site 50, Nulla Station, on lunette on E. side of Lake Victoria, N.S.W.
14. **7200 ± 140 yr B.P. (GaK-2513).** Small log of *Eucalyptus largiflorens* (Black Box) determined by Mr. H. D. Ingle, C.S.I.R.O., on wood structure. The engineer overseeing the test trench for a bituminous groundwater cut-off curtain at the Chowilla Dam

site (S. Aust.) showed me the heaps of sediment samples from various depths that he prepared for contractors. The fossil wood came from the sample covering 7·5-10·5 m from the surface (25-35 ft). The log was about 10 cm in diameter so that there is a small factor of biologic age.

15. **7210 ± 160 yr B.P. (GaK-1726).** *Velesunio* shells from Aboriginal midden between the A and B horizons of surface red (5 YR 6/4) soil on E. side of Triple Swamp Gulch, Moorna Station, N.S.W. The A horizon has therefore suffered stripping, then been replaced. This history is reflected in the lack of compaction in the A horizon, viz. 2-4 kg/cm^2 (B horizon 4-8·8 kg/cm^2 but harder in zones of secondary carbonate deposition). The shells were excavated by Sir Robert Blackwood from 0·5 m^3 of sandy soil during the survey of the gulch (Fig. 24).

16. **9160 ± 340 yr B.P. (GaK-2921).** Bone apatite from bones of extinct marsupial collected 30 Oct. 1968 by H. E. Wilkinson from Nulla Nulla Sand in lunette on Nulla Station, E. side Lake Victoria, N.S.W. The sample of about 700 gm included an imperfect tibia, scapula and metatarsal of *Protemnodon*. Bones had a carbonate encrustation such as is not seen on bones from the Talgarry Sand. Site 50, from blow in interfluve 4-5 N. In view of the current discussions on apatite datings, this result should not be taken too literally. However, it is consistent in that it falls between the limiting dates for the Nulla Nulla Sand of 6,360 and 17,530.

17. **11,250 ± 240 yr B.P. (GaK-1062).** Selected thick pieces of well-preserved *Velesunio* shell from base of large Aboriginal midden on top of high cliff on left bank of Murray River at Redcliffs, Victoria (34° 19'S, 142° 17'E). The cliff sections a high terrace. The antiquity of the midden was originally surmised from the degree of compaction, and that the midden was sectioned by the high cliff.

18. **12,600 ± 1300 yr B.P. (ANU-404B).** Charcoal from Aboriginal mussel shell midden associated with sample 404A (dated 24) which dated 17,530 yr. Sample was only 7% of requirement.

19. **14,200 ± 790 yr B.P. (NZ R2729/1).** Earthy carbonate from 0·6-0·9 m in auger hole (No. 2) sunk through top of an E-W. dune of the Woorinen Formation c.1 km SSW. of Berribee Station homestead (Fig. 10), NW. Victoria. (Sample CHG 88/33). Dr. T. A. Rafter, D.S.I.R. Institute of Nuclear Sciences, advised that the concentration of CO_2=10·5%, and $\delta^{13}C$-2·6$^0/_{00}$.

20. **15,300 ± 500 yr B.P. (GaK-2515).** Charcoal from large Aboriginal midden in Nulla Nulla Sand containing also *Velesunio* shells (date 23), bones including *Onchogalea frenata*, a gastrolith and a quartzite scraper. The site is near the end of the track shown on the Ana Branch Military map that finishes at the N. shore of Lake Victoria. The ruins of an hotel stand there. and the midden is c.1 km E. of the old hotel, Nulla Station, N.S.W. The midden was still partially covered by compact Nulla Nulla Sand as seen in Fig. 48. The midden measured 13 x 6 m and was very compact. It was 15 cm thick and stratified with lighter and darker layers. Site 52, sample CHA/248. Some burnt bone was present. Bones are rare in shell middens as the vertebrates were usually cooked in the ovens represented now by small heaps of burnt stones with charcoal. This may be the reason why bones of a small animal only were found in this site. The midden site was surveyed to a Chowilla Dam Survey bench mark, which had a compass bearing of 148° therefrom, was 100 m (328 ft) distant, and 4·1 m lower. This is the N. limit of the lunette, which cuts out at the ridge traversed by the track to the old hotel. W. of that is a large erosion amphitheatre which we called the Old Hotel Amphitheatre.

21. **15,900 ± 275 yr B.P. (ANU-405).** Shells of *Velesunio* from an Aboriginal midden in a stratified context in the lunette on the E. side of Lake Victoria, N.S.W. The midden is at the head of gulch 18 on Nulla Station near the marker peg N18. A small mesa of Nulla Nulla Sand stands over the midden to a depth of 4·55 m. The flat top is due to a paleosol. The sample (CHA/330) was excavated from the midden. Human bones were found at the outcrop of the midden, and it appeared that they could come from nowhere else as they were in among the loose shells, but they were not *in situ*.

450

22. **16,400 ± 560 yr B.P. (GaK-3218).** Earthy but solid carbonate (i.e. sand lithified with carbonate) from section of E-W. dune exposed on the W. roadcut of the Calder Highway (Melbourne to Mildura), 3·2 km N. of Ouyen, Victoria. Sample from B horizon of paleosol 76-94 cm from surface. Another paleosol 0·7 m lower in the dune was not dated (see morphology section re dunes). Collected 15 May 1969.

23. **16,720 ± 260 yr B.P. (ANU-422).** *Velesunio* shells from Aboriginal midden c.1 km E. of old hotel site on N. shore of Lake Victoria. See date 20 above for charcoal from same site, and discussion of chronology. Sample CHA/248.

24. **17,530 ± 320 yr B.P. (ANU-404A).** *Velesunio* shells from second last gulch in lunette on SE. shore of Lake Victoria, Talgarry Station, N.S.W. Sample from red paleosol in Nulla Nulla Sand (Fig. 44) where a blowout occurred later infilled with Talgarry Sand. These blowouts may have taken place during the Postglacial thermal maximum (see date 13 above). Sample CHA/320. δ C^{13}%ó 0·0 ± 2·0. When this date is taken with No. 13, it can be seen that the top of the Nulla Sand varies from 6,500 to 17,500 yr according to how deep erosion has cut into that Member.

25. **18,200 ± 800 yr B.P. (GaK-2514).** Aboriginal midden consisting of compacted fine charcoal with mussel shells in hollow in sand of gulch (Fig. 47) on NW. shore of Lake Victoria (Noola Station), N.S.W., near fossil bettong bones. Sample CHA/289. This is the oldest midden dated in this area. With time the pieces of charcoal of a midden break down and become a compacted mass of fine carbon. After weaken-

ing by bacterial action (surfaces progressively retrograded by oxidation of the carbon to carbon dioxide), the charcoal collapses and compacts as a result of ground pressure.

26. **27,500 ± 700 yr B.P. (N.Z. R2729/4).** Soil carbonate from near carbonate nodule quarry between 309 and 310 mileposts on E. side of Calder Highway S. of Hattah and Mildura, Victoria. The road is cut through an E-W. dune. An auger hole was sunk through the dune to obtain *in situ* samples of sediments and paleosols (see log and comment in section on dunes under Geomorphology). X-ray showed the mineral to be calcite, and that quartz was present.

27. **27,800 ± 1900 yr B.P. (GaK-1727).** Outer 5 mm of large carbonate soil nodule (c.12 cm diam.) consisting of laminated calcite. This zone encloses an older generation of small nodules (date 30). Sample from bank at N. end of Moorna E. oxbow (Site 13), Moorna Station, N.S.W. At this site, carbonate nodules are excavated for roads.

28. **28,000 ± 1800 yr B.P. (GaK-1728a).** Inner part (5-10 mm) of laminated cortex of soil carbonate nodule from Moorna E. oxbow (date 27). The difference in figures between assays 27 and 28 does not necessarily mean that there is an appreciable difference in age. See discussion in paper on palaeopedology. The core of this same nodule was beyond the range of the radiocarbon dating method used (date 30).

29. **31,300 ± 1,200 yr B.P. N.Z. R2729/2.** Soil carbonate from auger hole 2 in E-W. dune on Berribee Station, NW. Victoria (detail under date 19), belonging to the Woorinen Formation. Depth 2·64-3·17 m.

30. **>31,700 yr B.P. (GaK-1728b).** Small nodules formed most of the soil carbonate nodule used for assays 27, 28 and 30 from Moorna Station, N.S.W. This sample from the centre of this compact calcitic nodule was beyond the assay range.

31. **>34,300 yr B.P. N.Z. R2729/3.** This is the third soil met in the auger hole through the E-W. dune on Berribee Station, Victoria, and is that occupying the surface of the terrain before the dune was built. See discussion of dunes in section on Geomorphology.

Comment: This is a small grid of dates for so large an area, but more were not possible. The dates are of course in "radiocarbon years" pending corrections (such as that for the half life of C14). The disparity between dates of over 30,000 yr assayed on marine carbonate, and dates on the samples given by the U/Th method, cause one to critically consider the dates on terrestrial carbonate in this same time range. Some kind of cross check is required. In an attempt to do this, sets of samples from the study area were sent to two laboratories with different approaches to see if they could apply successfully the U/Th methods described by Kislitsina and Cherdyntsev (1967) and by Hansen and Stout (1968). No positive results have been obtained so far. Nevertheless, it must be significant that the many carbonate C14 terrestrial dates known to me, all fall in the correct order where there is stratigraphic superposition. I introduced dating of terrestrial pedologic carbonates in 1964 when working on the geology of the Talgai Cranium (Darling Downs, S. Queensland). At that time, carbonates were not usually believed to be of any use for radiocarbon dating, but as no other materials were then available, it was decided to try them out. The reasoning was that the bedrock had been leached by lateritization, and that the carbonate in the shells and nodules originated in Tertiary basalt in the headwaters of the streams. This was taken into solution, so releasing the original carbon dioxide. The mollusca in the stream incorporated the CaO in their shells, but using modern carbon dioxide. Assay of modern mussels from the same river system collected prior to atom bomb tests proved this to be so (Institute of Nuclear Sciences, N.Z.). Such shells in stream terraces were used for dating. Fossil shells incorporated in riverine sediments are dissolved by soil acids, and the CaO redeposited in the B horizon as nodules, utilizing soil air. Such nodules were the second type of material used for dating.

In addition to the stratigraphic series, centres and outer layers of some nodules were dated. These also gave dates in the correct order of age, and up to 2,000 yr difference was found between outer layer and core. The mineral was calcite, and petrologic examination by C.S.I.R.O. (Dr. G. Baker) showed that no re-crystallization had occurred.

In putting perspective into events in the study area, the radiocarbon dates elucidated certain processes. For example, the dynamics of the region are such that all the Quaternary sands are of similar grade (see section on sedimentation). The radiocarbon dates show that with time there is an increase in compaction for such sands when in similar environments.

5. *Paleosols*

The significance of these pedoderms for

chronology and palaeoecology is discussed in an accompanying paper.

6. *Fluorine Test.*

The Chief Chemist of the Division of Agricultural Chemistry, Mr. J. O'Brien, kindly arranged for the analysis of a series of fossil bones collected during the Chowilla Project, and the results are given in an accompanying paper by Mr P. J. Sinnott. For chronology the Fluorine Indices (for definition see Gill 1954) and the percentage of nitrogen are significant. These figures with stratigraphic detail and some interpretation are set out below. The sample numbers are as in the Sinnott report.

1. Piece of fossil fish from 0·9-1·2 m above Chowilla Sand, in the erosion amphitheatre S. of the homestead on Noola Station, situated on the NW. side of Lake Victoria, N.S.W. Site 6.
2. Fragments from large marsupial pelvis in Moorna Formation (or base of associated Chowilla Sand, which were not distinguished at the time), Fisherman's Cliff, Moorna Station, N.S.W. Site 13.
3. Bone from Chowilla Sand under Blanchetown Clay at Bone Gulch, Moorna Station, N.S.W. Site 12.
4. Fragments of *Procoptodon goliah* from Rufus Formation on the property of Mr. J. Curtis, 'Karawinna', on Boy Creek, Lot 22 Parish of Tulillah, Victoria (Fig. 4).
5. Fragments of large marsupial from Rufus Formation between Frenchmans Creek and the Wentworth-Renmark road, Dunedin Park Station, N.S.W. Site 10.
6. Fragments of marsupial bone from interfluve N14/15, lunette on E. side of Lake Victoria, Nulla Station, N.S.W. in Nulla Nulla Sand. Site 8.
7. Fragment of *Procoptodon goliah* from Nulla Nulla Sand, Talgarry Station, N.S.W. Site 9.
8. Piece of bettong bone from Aboriginal midden in Nulla Nulla Sand, E. of Old Hotel site, Nulla Station, N.S.W. Site 7.
9. Marsupial bone from Talgarry Sand, 0·9-1·2 m above base of formation at interfluve 13/14N, Nulla Station, N.S.W. Site 8.
10. Fragments of human skeleton lightly cemented with carbonate in the surficial 'indurated layer' of a hillwash fan in the erosion amphitheatre SW. of the homestead, Noola Station, NW side of Lake Victoria Site 6. Sample CHA/288.
11. Fragments of human skeleton (field number 6/0) collected 26 Apr. 1967 from Lybra Paddock, Keera Station, N.W. Victoria. CHA/35.
12. Fragments of human skeleton (field number 1/B), Brown's Paddock, Keera Station, N.W. Victoria. CHA/8.
13. Fragment of holotype of *Zygomaturus victoriae* (S. Australian Museum P4986) from Lake Victoria Station at the time it consisted of all the country in the Lake Victoria area. Mr. K. Crozier of 'Warrakoo' and Mr. D. Harvey of 'Nulla' kindly checked the matter, and the well from which the fossil came (depth '45-60 feet') was probably to the north of the lake. The formations of the riverine tract are not involved, so it must have come from the Blanchetown Clay, the Chowilla Sand or the Moorna Formation. It did not come from the first formation, because it is brown in colour and not whitish like the bones found therein; also the bones are undisturbed whereas those from the Blanchetown Clay seen by us are distorted due to movements of the clay (which contains montmorillonite). In the study area the Chowilla Sand interdigitates freely with the Blanchetown Clay. The Fluorine Test and the Nitrogen Test do not distinguish between the Chowilla/Blanchetown and the Moorna formations, so it cannot be said (on this evidence) whether the holotype comes from the Chowilla Sand or the Moorna Formation. However the Chowilla Sand is always oxidized and the Moorna Formation usually not, so the fossil (being brown) is more likely to belong to the Chowilla Sand. So far efforts to locate the exact site have not been suc-

cessful, but if they are, then the depth will give some indication which formation is involved.

14. Fragment of bone from National Museum of Victoria specimen P29500.
15. Fragment of bone from National Museum of Victoria specimen P28882.
16. Fragment of bone from National Museum of Victoria specimen P29502.

Specimens 14-16 are from the Moorna Formation and associated Chowilla Sand, Fishermans Cliff, Moorna Station, N.S.W. Site 13.

The results of the assays according to formations, and the radiocarbon dates where available (for control), are:

Formation	*C14*	*Fluorine Index*	*% Nitrogen*	*Sample number*
A. Indurated layer (no formational name)	<200 yr	2.28	0.226	10
B. Talgarry Sand	<6400 yr	6.86	0.026	9
C. Nulla Nulla Sand	6400-18,000+ yr	6.62	0.043	6
		9.73	0.020	7
		1.89	—	8
D. Rufus Formation	? Mid. Pleistocene	5.53	0.045	4
		5.09	0.041	5
E. Intrusive in Rufus Formation	4000-6000 yr	2.45	0.041	11
		1.81	0.118	12
F. Blanchetown Clay	Pliocene/Pleistocene	16.94	0.019	1
G. Moorna Formation	Late Pliocene	16.42	0.013	2
		20.58	0.007	3
		14.09	—	14
		17.15	—	15
		19.06	—	16
? Moorna Formation		14.80	—	13

The Fluorine Indices as a group are high, but the reason for this is not understood. However, they show an increase with age, and the percentage of nitrogen falls off with age. There is thus a general relative dating, but the chief value of such tests is to discover samples that are out of context. Thus clearly sample 8 is wrong. The bone belongs to a bettong, a burrowing marsupial, so perhaps it is intrusive. The human remains in the Rufus Formation (samples 11 and 12) are also clearly intrusive. The disconformity between the Blanchetown Clay and the formations in the incised river valley is made clear by the jump in fluorine indices and the drop in nitrogen percentages. The Blanchetown Clay and the Moorna Formation are conformable, the former overlying the latter. This is reflected in the very similar figures.

Sedimentation

"To see a world in a grain of sand" William Blake (Auguries of Innocence)

The development of geophysics made possible the discovery of the fundamental structure of the earth's crust. Investigations led to the differentiation of the heavier oceanic crust and the lighter continental crust. So evolved the concept of the continents as rafts of sial floating in a sea of sima.

Later, the demonstration of a far greater horizontal mobility for the crust than previously envisaged, the discovery of mid-oceanic ridges with evidence of spreading, and the need for some other explanation of tectonics and vulcanism than as expressions of a shrinking earth, led to new credence being given to Wegener's hunch of continental drift. Wegener did not prove it, nor is it now proved. However, it is true that the supporting evidence has been very greatly increased. During the past 10 years there has been such a rapid accumulation of data and so fast a flurry of changing ideas that this is clearly no time for dogmatism.

The calving of land masses (e.g. Australia from a southern supercontinent), and the collision of continents are vast traumatic events which must leave major lesions on the skin of the earth. On the other hand, there are many long slow warpings of the crust with associated accumulation of sediments that are of quite a different order of dynamics. Such is the Murray

Basin. Although cheek by jowl with the massive fault system that yields the Mt. Lofty Ranges of Precambrian sediments, the Murray Basin has very slowly subsided over more than 120 m.y. The mean rate through this period in the deepest part of the basin (and so the fastest sinking) is only 1 m per 120,000 yr. At this maximal rate, the land would sink only 8·3 cm in the whole of the Holocene (10,000 yr). It is no wonder that the surface of the Murray Basin is so flat and its dynamics so low. This is the background against which to view the grain size analyses. However, the factor of tectonicity (cf. Krumbein and Sloss 1963) has been qualified by climatic change (see section on palaeoclimatology), for a humid region has become a semi-arid one.

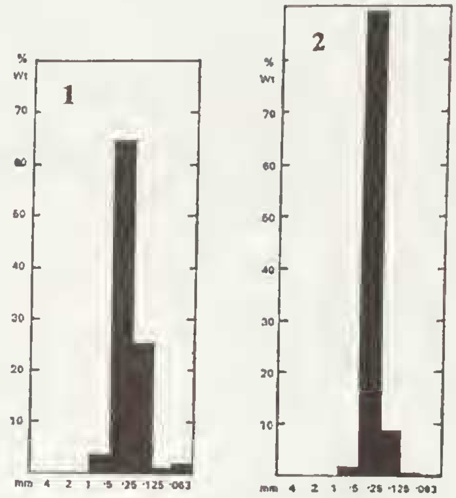


Fig. 49—Grain size analysis histograms of Parilla Sand. 1 = Gray clayey sand at base of Murray R. cliffs, Kulcurna Station homestead, Cal Lal. N.S.W. Sample CHG 78. Site 2 = Same site. 3·7 m below top of formation. Sample CHGSS 115. For section see Fig. 19.

Grain Size Analyses

Unless otherwise stated, the sieving has been carried out by Mr. K. G. Simpson and assistants under the direction of Dr. A. W. Beasley, Curator of Minerals, National Museum of Victoria, whose research lies in this field. The integration and interpretation of these results are the writer's responsibility. I am indebted to Dr. Beasley for his considerable assistance. Mrs. J. Dudley checked the calculations and drew most of the histograms.

Enquiries indicate that communication would best be served for those in the many disciplines interested in this report if the results are given in the form of histograms. These are numbered, and in general follow from the oldest to the youngest sediments. Wentworth's size classification is used.

Parilla Sand

This formation outcrops in the Murray River cliff beside the Kulcurna Station homestead (Fig. 19). The sediments are gray (unoxidized) and without reaction to acid. The formation was sampled at two levels:

1. Clayey sand at base of cliffs. Sample CHG/78.
2. Same 3·6 m from top of formation (6 m exposed). CHG SS 115.

Histograms 1-2 (Fig. 49) show well-sorted sediments with better sorting higher in the formation. Histogram 2 is remarkably like that for the overlying Chowilla Sand (Histogram 9, Fig. 53) which suggests that one was derived from the other, or both came from a common source by a transport system of like dynamics.

Moorna Formation

Histograms 3-6 (Fig. 50) are of Moorna Formation sediments in the section at the W. end of Fishermans Cliff (fossil bone site). Histograms 4-5 are of the same sample, and their close similarity is taken to mean reliability of analysis. They are unusually coarse for this region, and represent a riverine channel deposit. The deposit cuts out laterally. The base of the Moorna Formation outcrop at this site is finer (Histogram 3) with the medium and fine sand columns dominant as against the dominant coarse sand column for the sediments above.

Histogram 6 represents an unusual sediment because many of the grains are coated with dolomite (see Segnit, this volume). The inference is that these were eroded from a bed of sandy dolomite such as occurs at Triple Swamp Gulch (Fig. 24). The grains are well rounded. Some fines make the histogram slightly bimodal. Figure 51 shows the change in grain

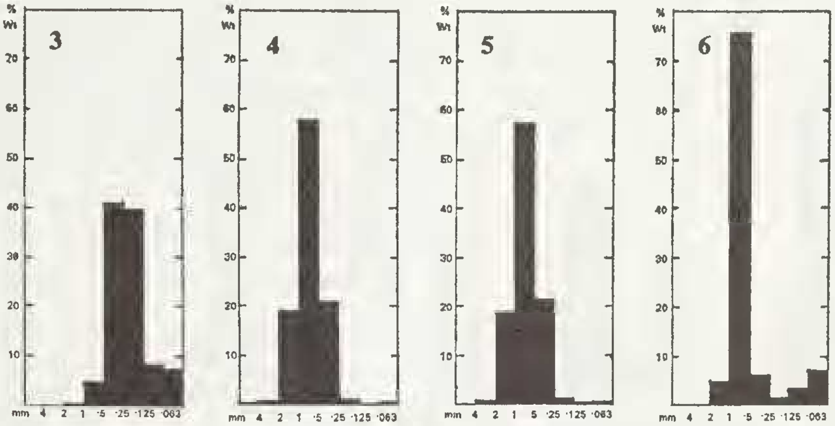


Fig. 50—Grain size analysis histograms of Moorna Formation sediments (see also Figs. 50-51). 3 = W. end of Fisherman's Cliff, N. bank. Murray R., Moorna Stn., W. of Wentworth, N.S.W. Fig. 30. Sample CHGSS 113. Site 13. 4 = Same site, clean sand at top with some grains dolomite-coated. See Fig. 51. The level is between the lower clayey part of the Moorna Formation and the overlying yellow Chowilla Sand with fossil tortoise. The sample is part of the matrix that carried the fossil bones described by Marshall in this *Memoir*; it came from c. 105 cm above the clayey sand (CHGSS 111).

size analysis when the dolomite is stripped by acid treatment.

Histograms 7-8 (Fig. 52) are of Moorna Formation sediments in two places other than Fisherman's Cliff. A brown (7·5 YR 5/6) sand at the base of the exposed section at Triple Swamp Gulch W. of Fisherman's Cliff gave histogram 7. The dominant grade is medium sand. Histogram 8 is of the thick light-gray sands in the Merbein Cliffs (Fig. 36). The grades of sand vary. This sample is from 0·6 m below the siliceous paleosol in the section at The Lookout. The spread of grades is rather similar to that of the Chowilla Sand into which it merges. The coarser sediments with current bedding occur lower in the section.

Chowilla Sand

Histograms 9-16 (Fig. 53) cover this formation, following sites from W. to E. No. 9 is remarkably similar to that of the underlying Parilla Sand (No. 2) and suggests derivation from it, or the same source. No. 10 shows the variation in the top of the formation. The major part of this deposit is homogenous with a slightly columnar structure. The top has sub-

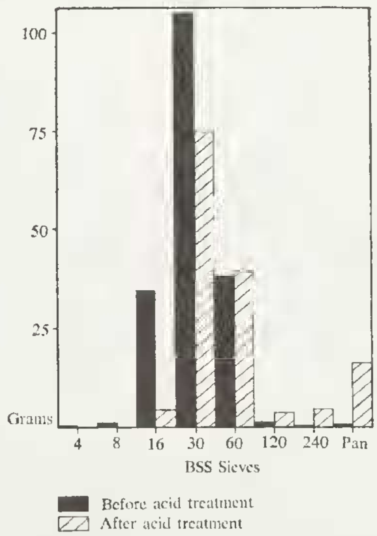


Fig. 51—Grain size analysis histogram of sediments from the Moorna Formation at the W. end of Fisherman's Cliff, Moorna Station, N.S.W. Site 13. Histograms 4-5 show the analysis of natural sand, while this figure shows the effect of stripping off the dolomite coatings.

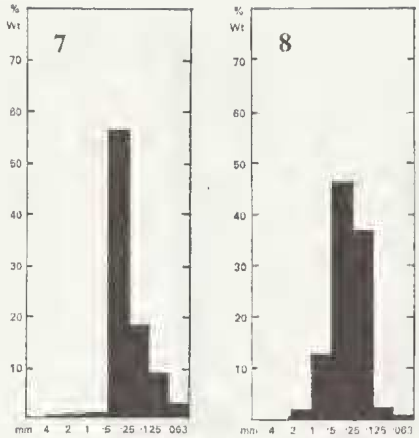


Fig. 52—Histograms 7-8 of grain size analysis of Moorna Formation sediments. 7 = White sand 0·6 m below top of formation (i.e. below the paleosol) in the cliff section at The Lookout, Merbein, V. Fig. 36. Sample CHGSS 108.

parallel bedding. No. 11 is from Nampoo Station in the Murray River cliffs where the Chowilla Sand is a narrow bed in the Blanchetown Clay sequence.

Dr. A. W. Beasley reports on the mineral composition of samples 13 and 14 as follows: "The sand samples are composed essentially of light mineral grains, most of which are quartz. Feldspar grains are generally cloudy from alteration, and some are almost opaque; they are often lath-shaped. White mica occurs in minor amounts; it is more common in the finer size-grades of the samples. The quartz grains in samples 13 and 14 are commonly iron stained in a patchy fashion, and inclusions are very numerous. The larger grains are subrounded to rounded, while the finer size particles are usually subangular. The degree of roundness of most grains indicates that they have had a fairly long detrital history."

Heavy Minerals

Dr. Beasley reports that "the assemblages consist essentially of the same species, but there are differences in their relevant proportions, the significance of which could only be determined by more numerous analyses. The suites indicate granitic and metamorphic source rocks. The opaque minerals are relatively common, while the non-opaque heavy minerals include zircon, tourmaline, hornblende, apatite, rutile, sphene, anatase, staurolite, garnet, epidote, andalusite, cassiterite and biotite. The degree of roundness of the heavy mineral grains varies considerably; most are subrounded or subangular. The weight percentages of heavy minerals in the 0·25 mm to 0·125 mm size grains are as follows:

Sample 13 0·20%
Sample 14 0·25%
Sample 17 0·13%."

Sample 14 has the lowest degree of sorting of all the Chowilla Sand samples tested. This may be due to being so close to the clay facies. At Bone Gulch there is a series of alternating thin beds of clay and sand. The sands have concentrations of fossil bones, and the highest percentage of heavy minerals. Ostracods are common, indicating shallow water. Some of the bones are worn. It is considered likely that these beds were deposited by an oscillating level of the lake, the higher levels washing the sands and concentrating bones and heavy minerals. The partly articulated bones of a large diprotodontid were found in the base of the Blanchetown Clay. The animal may have been mired in shallow water.

Histogram 15 is of a sample from the Yelta cliffs which likewise has a comparatively poor degree of sorting . Histogram 16 is of a sample from the Merbein cliffs, and shows a dominance of medium and fine sand grades seen also in other samplings of this formation.

Blanchetown Clay

Histograms 17 and 18 (Fig. 54) are of samples from this formation (with the clay removed). Sample CHG SS/42 (No. 17) is from just above the ossiferous Chowilla Sand at Bone Gulch, Moorna Station, N.S.W. The sediments are poorly sorted with three modes—clay (69%), silt and fine sand. Histogram 17 for material greater than clay size is bimodal, with a primary mode in the fine sand grade and a lesser one in the silt. Dr. Beasley reports "The

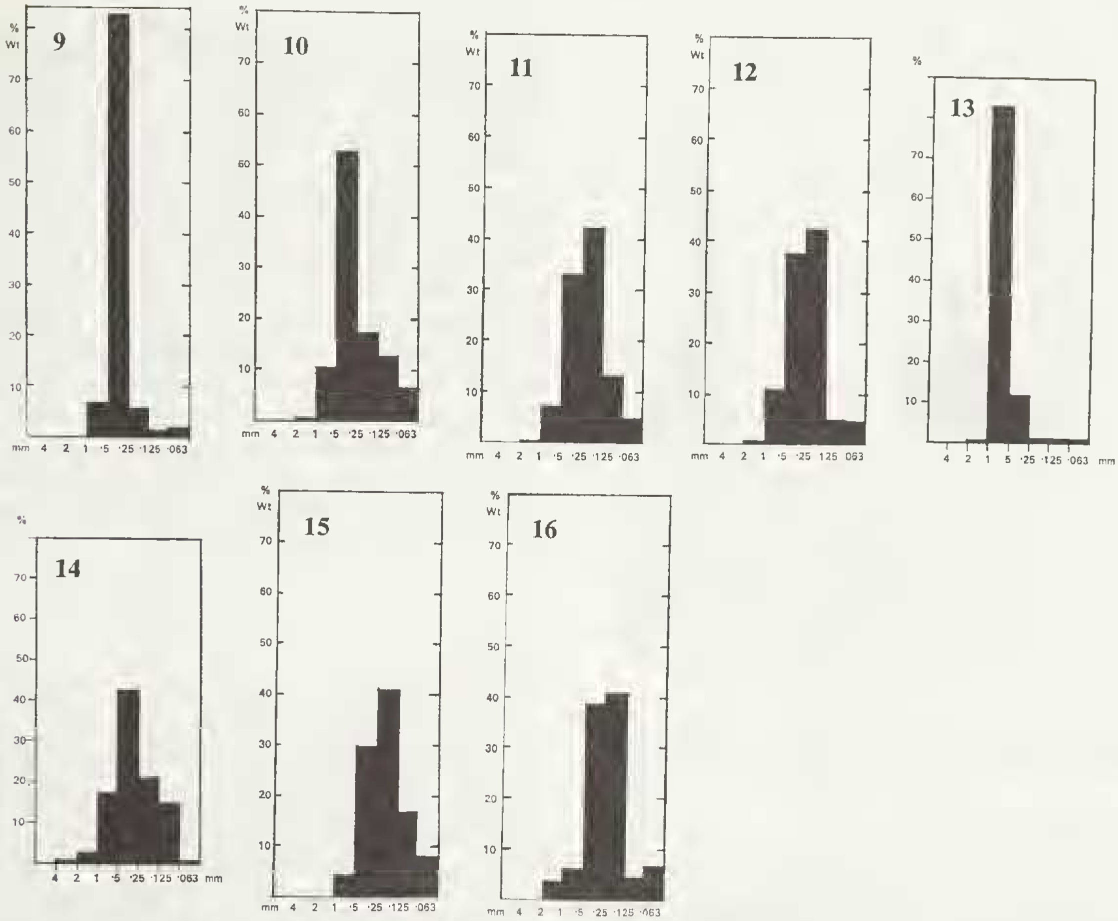


Fig. 53—Histograms 9-16 of grain size analysis of Chowilla Sand. 9 = Upper part of Murray R. cliff at Kulcurna Stn. homestead, Cal Lal. N.S.W. Site 3. Fig. 19. Sample CHG 38. 10 = Same site, but sample from cliff top. CHG 77. 11 = Under Blanchetown Clay at foot of cliffs below Nampoo Stn. homestead. E. of Cal Lal, N.S.W. 12 = Sand below Blanchetown Clay, Middle Gulch. Noola Erosion Amphitheatre, Noola Stn., NW. side of Lake Victoria. Site 6. W. end, Fisherman's Cliff, Moorna Stn., N.S.W. Sample CHGSS 43, 15 = Middle of sand formation at top of cliffs, S. bank Murray R., at Yelta, Vict. See Gill on Palaeopedology, this *Memoir*, Fig. 1. 16 = Chowilla Sand between Blanchetown Clay and Moorna Formation in Merbein Cliffs, Vict., at The Lookout. Fig. 36. Sample CHGGS 114.

material greater than clay size is mainly quartz. Although inclusions are numerous in the quartz, the grains are comparatively free from iron staining. They are cleaner than in the sand samples. Ostracods are fairly common. Felspar grains are cloudy from alteration. Flakes of white mica are present but not common. The suites of heavy minerals indicate granitic and metamorphic source rocks. The weight percentage of heavy minerals in the 0.25 mm to 0·063 mm grade is 0·13. The underlying Chowilla Sand has 0·25%".

A sample of Blanchetown Clay from the Murray River cliffs at Nampoo Station, E. of Cal Lal, N.S.W. had 90% clay, so the range of clay content in this formation is considerable. Within the Blanchetown Clay are bands of sand which vary from white (well-washed) to greenish gray (containing clay).

Histogram 18 (Fig. 54) shows the sample CHG 151a (after washing) from a sandy layer in Noola erosion amphitheatre on the NW. shore of Lake Victoria. The analysis is dominated by the fine sand grade, and so represents

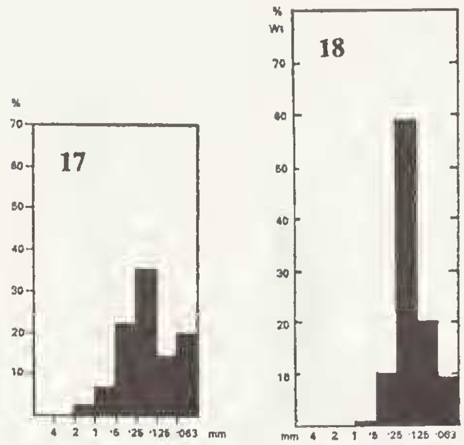


Fig. 54—Histograms 17-18 of grain size analysis of washed samples of Blanchetown Clay. 17 = Clay from Bone Gulch. Moorna Stn. (Fig. 34), W. of Wentworth, N.S.W. 18 = Sandy layer in this formation with *Corbiculina*, Noola Erosion Amphitheatre, Noola Stn.. NW. side Lake Victoria (Fig. 17), N.S.W. Sample CHG 151a.

an environment of low dynamics. The bed had numerous shells of the bivalve *Corbiculina*.

Woorinen Formation

1. *Berribee Station Dunes*. An auger hole put down through an E-W. dune provided the samples which yielded the histograms 19-26 (Fig. 55). They all show good sorting with fine sand being the dominant grade. All the histograms are unimodal except 24 and 26 which are bimodal. It would be interesting to know if the bimodal zones can be traced from dune to dune.

2. *Hattah Dune*. Histogram 27 (Fig. 55) of sediment from the Hattah district, but in the same system of E-W. dunes, gave a similar result.

Histogram 24 (sample 36 from 3·4-4 m) is the best sorted (SO=1·3) yet is bimodal with 21·59% silt. The base of the dune is represented by histogram 25 (sample 37 from 4·6-5·5 m) which is skewed to the fine side. Samples 36 and 37 had 11·9% and 5·70% of clay removed before the grain size analyses were commenced. The clay content is believed to be (1) partly blown in with the original sediments as clay skins on sand grains, and as aggregations, and (2) partly added later from dust storms. The increase in clay content at the base is believed to be due (1) partly to washing down of clay by rain water, and (2) partly to the dune overlying a very clayey substrate which probably contributed a good deal of clay in the initial stage of dune building. Histogram 26 (sample 38 from 5·5-5·7 m) represents part of the old terrain on which the dune was built. It shows the typical dominant fine sand column, but with a silt column almost as high. The histogram is thus bimodal. To gain the sample for grain size analysis 57·92% of clay was removed from the field sample. A floodplain lagoon or a lake is indicated, because 83% of the field sample was fine enough to pass through BSS sieve 240.

Rufus Formation

1. *Dunedin Park Station, N.S.W.* Figure 37 provides a surveyed section across the margin of an outlier (number 1 in Fig. 5) of this formation near Frenchman Creek. This outlier is a remnant of a higher Pleistocene terrace of the Murray River. Its sediments are now oxidized to a red colour, that contrasts with the greenish gray sediments of the present floodplain. No doubt the Rufus Formation was once that colour too. Four auger holes were sunk along the section line. For logs see under Rufus Formation in stratigraphy section. Histograms of the sediment analyses are given in Fig. 56 as follows:

Histogram	28	Outlier 1, Auger 1,	0-20cm
	29		20-46cm
	30		61-69cm
	31		0·94-1·02m
	32		1·22-1·52m
	33		1·80-1·88m
	34		1·88-2·13m
	35		2·21-2·36m
	36		2·67-2·74m
	37		2·74-2·90m
	38		3·00-3·07m
Histogram	39	Outlier 1, Auger 2,	0-15cm
	40		53-61cm
	41		86-94cm
	42		1·22-1·35m
	43		1·75-1·83m
	44		3·76-3·84m

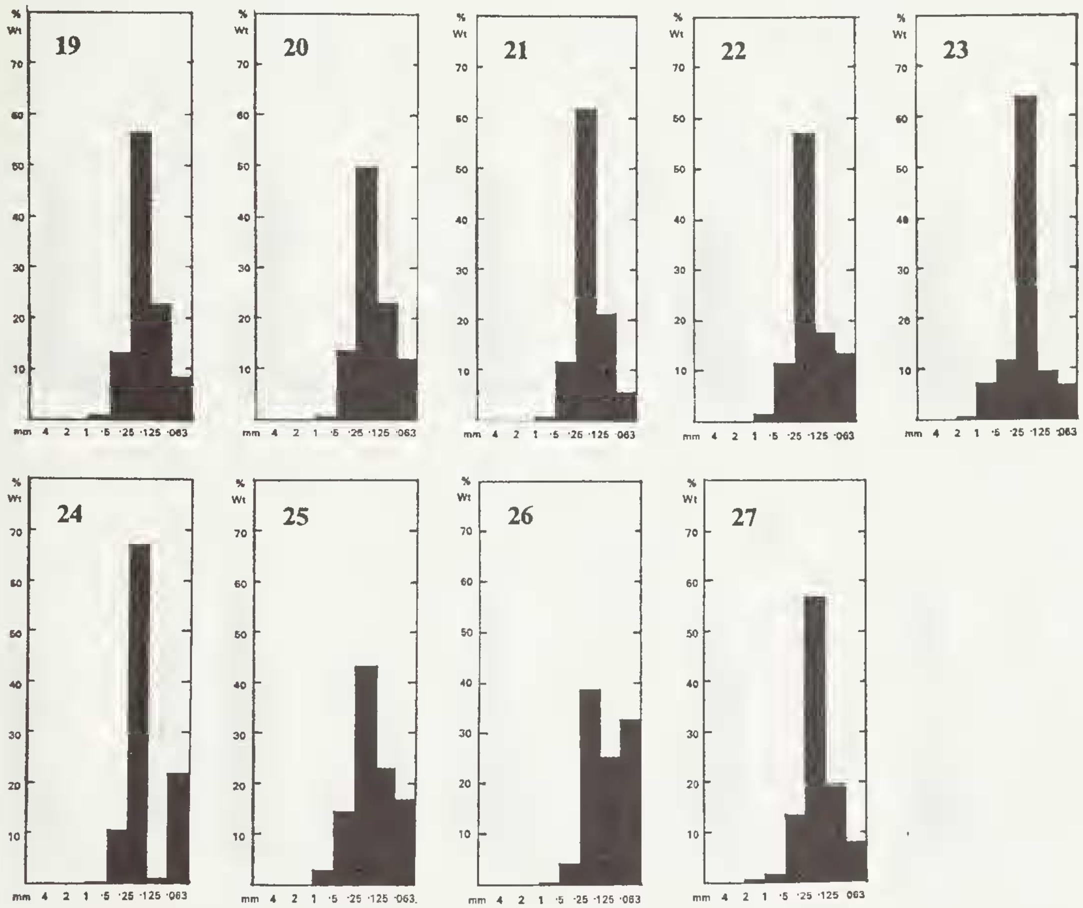


Fig. 55—Histograms 19-27 of grain size analysis of sediments from the Woorinen Formation (Pleistocene E-W. dune system). 19-26 from Auger hole 2 through dune c 3 km SSW. of Berribee Stn. homestead, Vict. CHGSS sample nos. in brackets.
19 = 0 — 0·38 m (32), 20 = 0·6 — 0·9 m (33), 21 = 2·3 — 2·6 m (34), 22 = 2·6 — 3·2 m (35), 23 = Repeat of 22, 24 = 3·4 — 4 m (36), 25 = 4·6 — 5·5 m (37), 26 = 5·5 — 5·7 m (38), 27 = Sediment from 2·6 — 2·9 m (118) in auger hole through E-W. dune, Calder Highway between mileposts 309 and 310, near Hattah, N. Vict.

Histogram	45	Outlier 1, Auger 3,	3·07-3·15m
	46		3·35-3·51m
Histogram	47	Outlier 1, Auger 4,	3·51-3·63m
	48		4·11-4·27m
Histogram	49	Outlier 1, Auger 4,	0-15cm
	50		36-46cm
	51		0·99-1·07m
	52		1·30-1·37m
	53		1·57-1·65m
	54		1·83-1·88m
	55		2·29-2·36m
Histogram	56	Outlier 2, Auger 1,	53-61cm
	57		1·32-1·42m
	58		2·44-2·54m

2. *Keera Station, Victoria.* Figure 38 is a cross-section of Rufus Formation structures at the E. end of Brown's Paddock (Site 17) Keera Station, Victoria, that at first glance look like dunes. They are extensions from a Pleistocene terrace remnant. Three auger holes were sunk as follows:

Auger 1 46⁺cm of gray well-washed mobile sand (which the auger could not lift) at the N. end of section (Fig. 38), local channel.

Auger 2 For site see Fig. 38.

50cm Red (2·5 YR 4/8) slightly clayey sand forming hardpan (surface sand deflated)

50cm Reddish brown (5 YR 5/4) and such clayey sand with glaebules of earthy carbonate up to 2 cm diameter. Gradually becomes grayer with depth till light gray (10 YR 7/2). Carbonate rich to 80cm then decreasing to 90cm

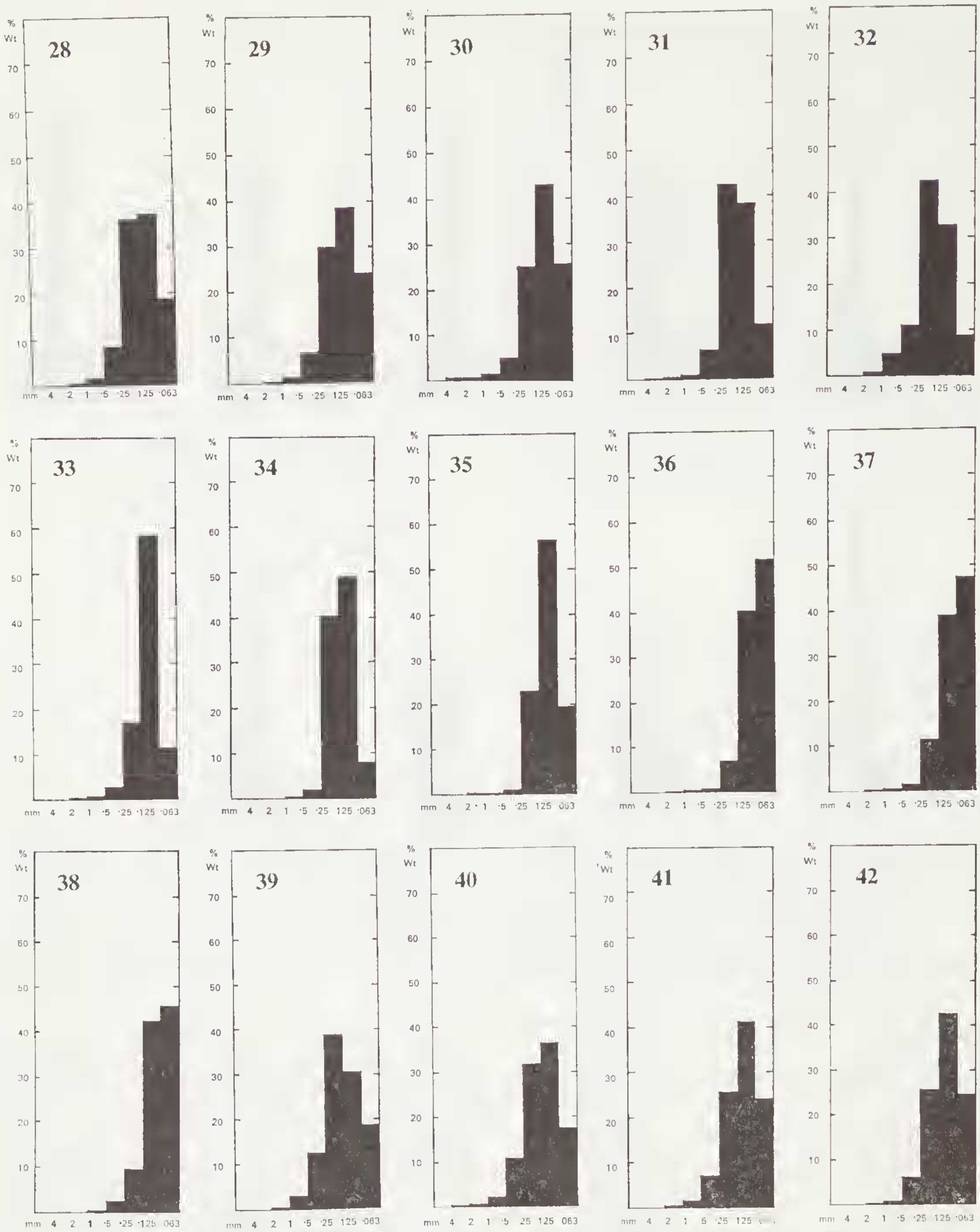
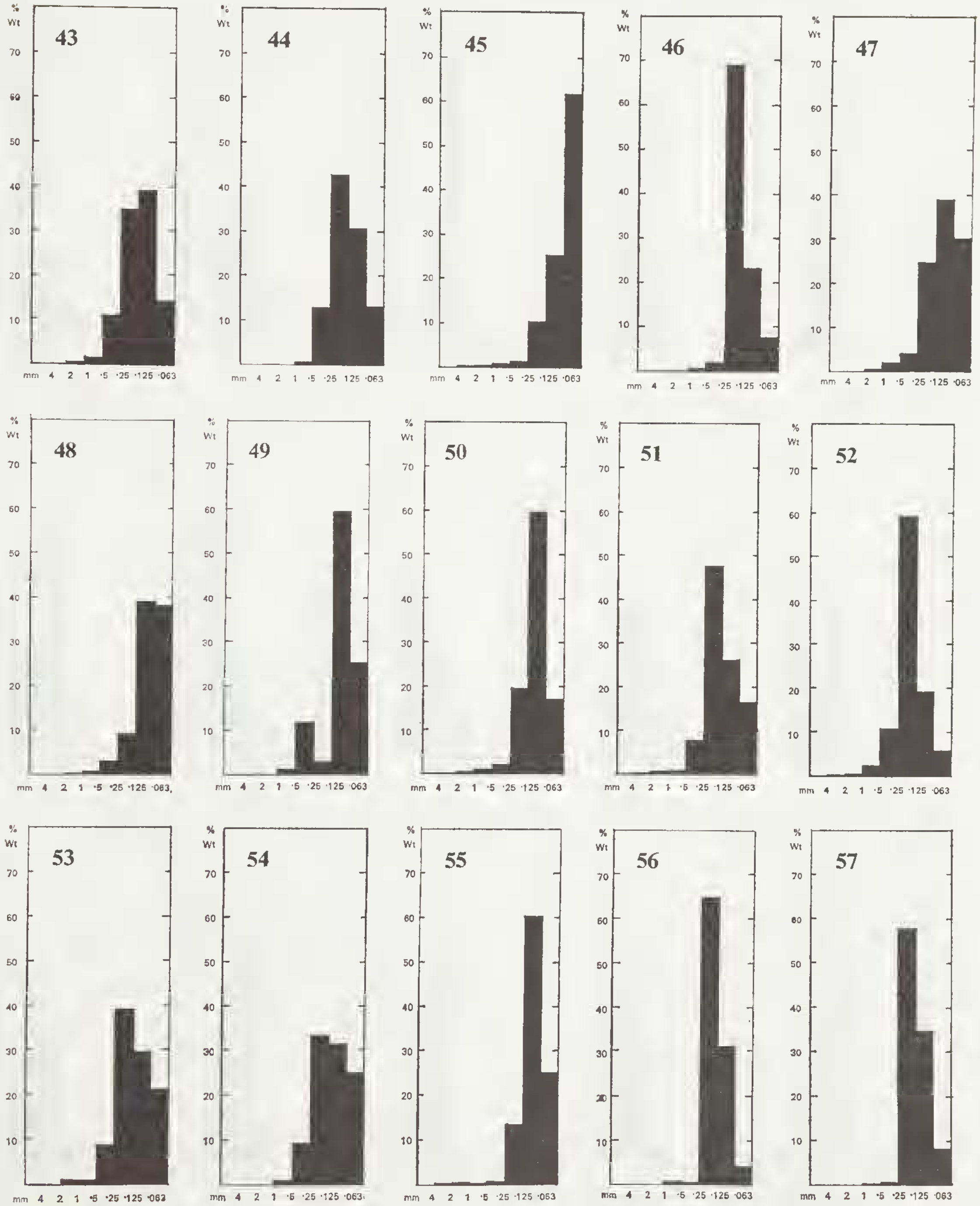
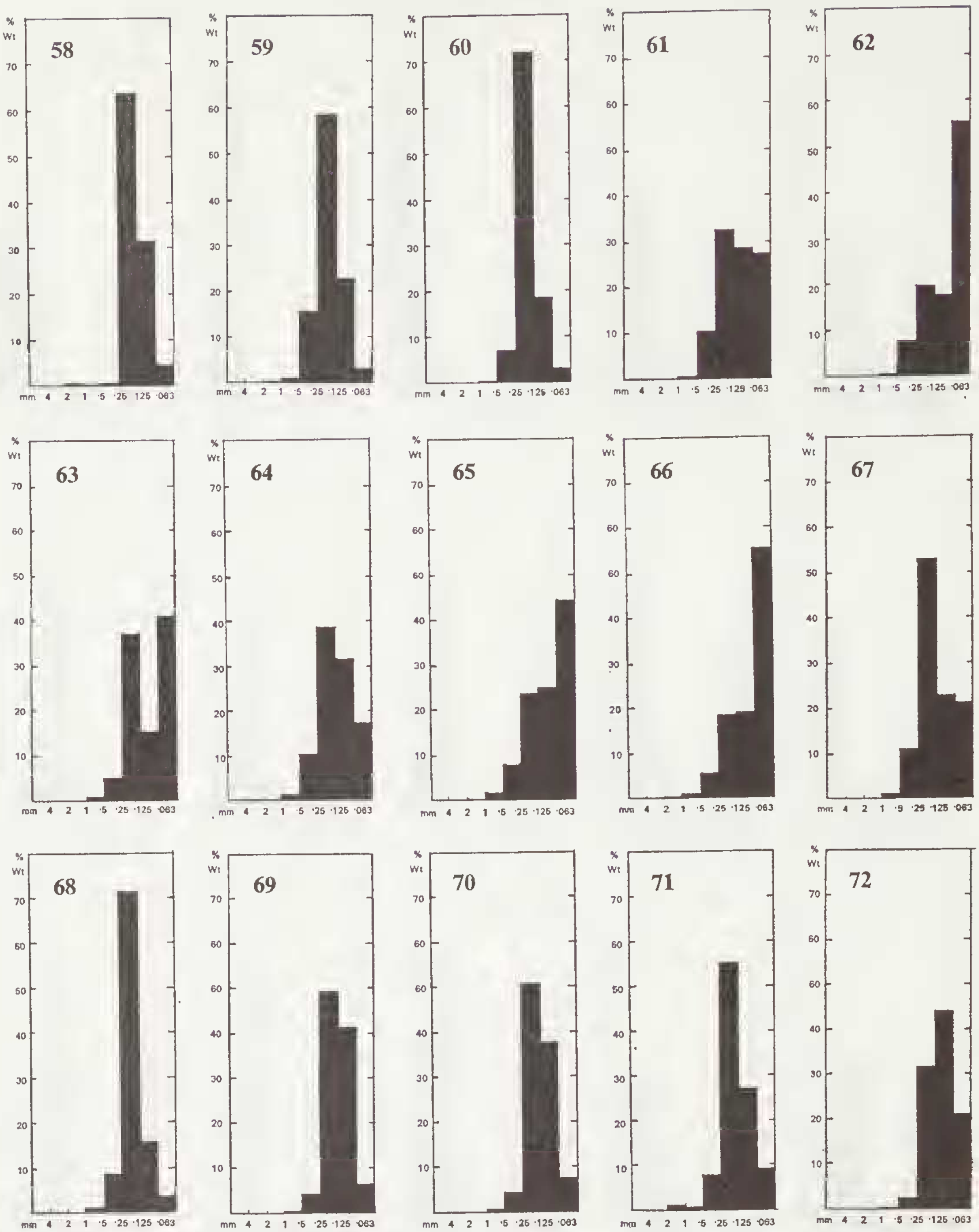


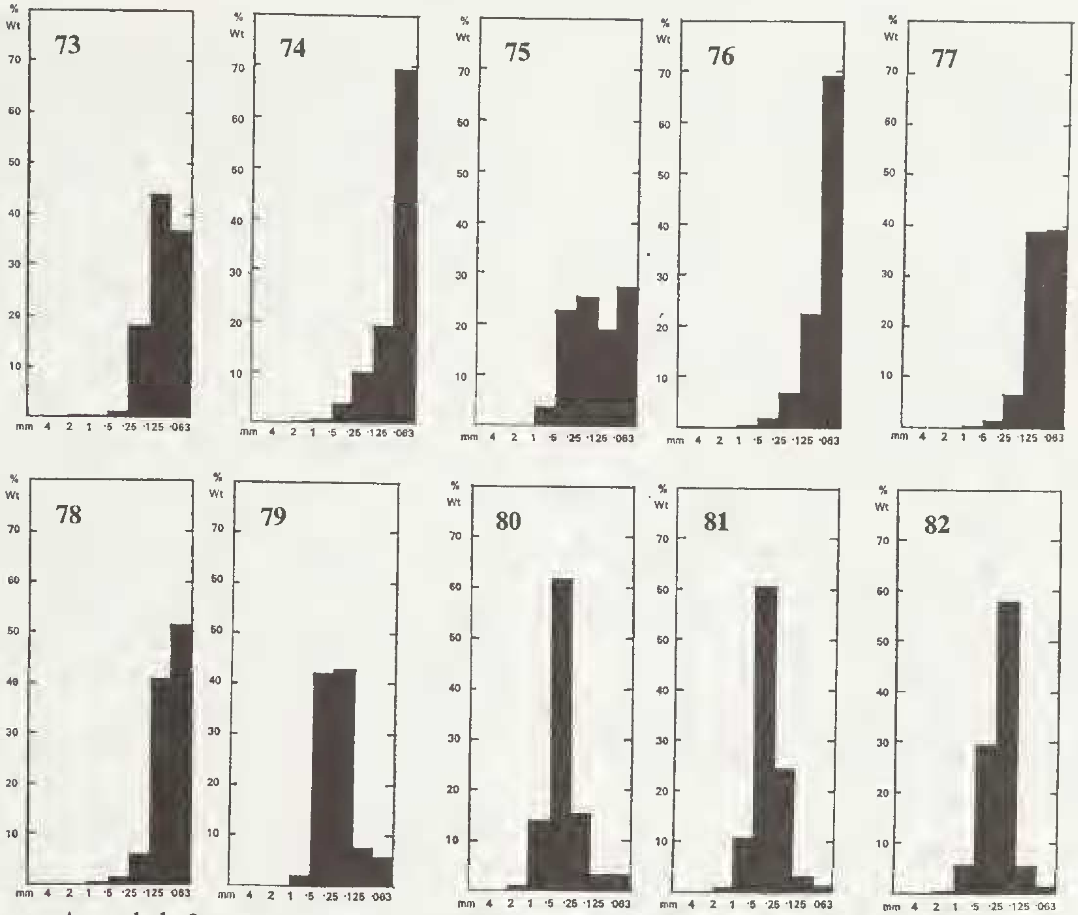
Fig. 56—Histograms 28-82 of sediments from the Pleistocene Rufus Formation (riverine). CHGGS sample numbers in brackets. Samples from auger holes in residual marked 1 on map in Fig. 5, Dunedin Park Station, N.S.W.
28 = 0 — 0·2 m (74), 29 = 0·2 — 0·46 m (75), 30 = 0·6 — 0·68 m (76), 31 = 0·94 — 1·2 m (77), 32 = 1·2 — 1·5 m (78), 33 = 1·8 — 1·9 m (79), 34 = 1·9 — 2·1 m (80), 35 = 2·2 — 2·4 m (81), 36 = 2·67 — 2·74 m (82), 37 = 2·74 — 2·89 (83), 38 = 3 — 3·07 m (84). See histograms 57-58.
Auger hole 2
39 = 0 — 0·15 m (85), 40 = 0·53 — 0·6 (86), 41 = 0·86 — 0·94 m (87), 42 = 1·22 — 1·35 m (88), 43 = 1·75 — 1·83 m (89), 44 = 3·76 — 3·83 m (91).



Auger hole 3A
45 = 3·5 — 3·63 m (100), 46 = 4·1 — 4·3 m (101).
47 = 0 — 0·15 m (92), 48 = 0·36 — 0·46 (93), 49 = 0·99 — 1·07 m (94),
50 = 1·3 — 1·37 m (95), 51 = 1·57 — 1·65 m (96), 52 = 1·83 — 1·88 m (97),
Auger hole 3
53 = 2·29 — 2·36 m (98).
Just W. of residual marked 2 in Fig. 5
54 = 0·53 — 0·6 m (102), 55 = 1·32 — 1·42 m (104), 56 = 2·44 — 2·54 m (105).
Auger 1, residual 1 (see histograms 28-38)
57 = 3·04 — 3·14 m (106), 58 = 3·35 — 3·5 m (107).



Surface soil, residual marked 1 in Fig. 5
59 = Loose red sand at surface, 60 = Sardpan below.
Brown's Paddock (Site 17), Keera Stn., Vict. (Fig. 38), auger hole 1
61 = 0·76 — 0·91 m, 62 = 1·98 — 2·13 m, 63 = 2·28 — 2·44 m.
Auger hole 4
64 = 0 — 0·41 m, 65 = 0·51 — 0·76 m, 66 = 1·02 — 1·32 m, 67 = 1·83 — 2·06 m,
78 = 2·44 — 2·69 m.
Lybra Paddock (Site 16), Keera Stn., Vict. Auger hole 1
69 = 0 — 0·43 m, 70 = 0·43 — 0·91 m, 71 = 0·91 — 1·6 m, 72 = 1·6 — 1·68 m,
73 = 2·74 — 2·92 m.



Auger hole 2
74 = 0·1 — 0·46 m, 75 = 0·46 — 0·66 m, 76 = 0·66 — 1·17 m (samples 74-76 were from the middle of the depth ranges given), 77 = 1·17 — 1·27 m, 78 — 1·27 — 1·55 m, 79 = 2·29 — 2·54 m, 80 — 2·74 — 3·5 m, 81 = 3·5 — 3·66 m, 82 — 4·57 — 4·78 m.

1·12m Zone of incipient mottles, some areas tending towards grayish green and others towards brown. At 2 m from surface gradual change to less clayey sediment

51cm Light yellowish brown (2·5 Y 6/4) sand. Probably more oxidized because more permeable

13cm More clayey and with light gray (10 YR 7/2) mottles.

84⁺cm Light yellowish brown (2·5 Y 6/4) sand.

Total depth 3·6m.

Auger 3 33·2m N. of skeletons (C14 site).

30cm Red (10 YR 5/6) loose sand without carbonate

45cm Red hardpan of same sand with clay; no carbonate

28cm Light gray to light brownish (10 YR 6/1) clay with off-white masses of earthy carbonate up to 1·5cm in diameter. Selenite crystals (needles)

94cm Similar sediment almost without carbonate

46⁺cm Same with pyrolusite.

2·43m Total depth.

Auger 4 On section line (Fig. 38) near samphire flat.

25cm Reddish brown (5 YR 5/3) slightly clayey sand forming a hardpan, merging to

5cm Same with carbonate merging to

30cm Pink (5 YR 7/3) to pinkish gray (7/2) clayey sand with glaebules of earthy carbonate pinkish white (7·5 YR 8/2), merging to

15cm Light brownish gray (10 YR 6/2) sand with less carbonate merging to

30cm Clayey sand, some colour, reduced carbonate; pyrolusite and gypsum appearing; merging to

1·07m Pale red (2·5 Y 6/2 and such) clayey sand

19⁺cm Light brownish gray (2·5 Y 6/2) to light 7/2) sand with yellow (2·5 Y 7/3 at 2·8m from surface.

Total depth 2·31m.

Auger 5 On section line (Fig. 38) in middle of samphire flat.

33cm Red sand blown and/or washed over flat, and some gray sand intermixed

15cm	Yellowish red (5 YR 5/6) clayey sand, some pyrolusite at top.
43cm	Pinkish gray (7·5 YR 3/2) sandy clay with numerous patches of earthy carbonate
56⁺cm	Light brownish gray (10 YR 6/2) sandy clay with a little carbonate and with selenite (rich at 1·07m from surface)
1·47m	Total depth
Auger 6	On crest of south ridge of section line (Fig. 38).
13cm	Light red (2·5 YR 6/6) slightly clayey sand forming hardpan
20cm	Red (2·5 YR 4/6) sand
1·27m	Pink (7·5 YR 7/4) sand with earthy carbonate glaebules up to 4cm diameter. Amount of carbonate reduced from 84 cm from surface merging to
46cm	Reddish yellow (7·5 YR 6/8) sand with finely divided carbonate
18cm	Dark brown (7·5 YR 4/4) sand with selenite and pyrolusite (which makes the sediment darker), merging over 5cm to
8cm	Pink (7·5 YR 8/4) sand with no appreciable amount of carbonate
1·19m	Light brown (7·5 YR 6/4) clayey sand—a marked increase in clay content
25⁺cm	Reddish yellow (7·5 YR 6/6) sand.
3·76m	Total depth.

The sediments from anger holes (2) and (3) were subjected to grain size analysis and the results are given in histograms 59-68 (Fig. 56) as follows:

Histogram	59	Site 1, loose red surface sand	
	60	Site 1, auger 3,	0-38cm
	61		76-91cm
	62		1·98-2·13m
	63		2·29-2·44m
	64	Site 1, auger 2,	0-41cm
	65		51-76cm
	66		1·02-1·32m
	67		1·83-2·06m
	68		2·44-2·69m

The auger holes prove that the profile is a stable one except for the mobile surface sand which was probably stable also before occupation by flocks of sheep. The profile has been stable long enough for the carbonate soil to develop, which (judging by the soil on the E-W. dunes) is at least 16,000 yr old. This soil occurs (with modification) on the flat as well as the ridges (Fig. 38), so no strong erosion can have occurred there during that period. Local information is that floods reach the end of the flat but do not penetrate between the ridges across the section line. The erosion of the former terrace (judging by the soil) must therefore have occurred prior to 16,000 yr ago. The terrace was eroded before the Lake Victoria Sands were deposited because they onlap outliers. However, more than halfway up in these largely subparallel blowout sands is a paleosol with a midden dating 17,530 yr B.P. If that figure is doubled, a chronology like that of the Lake Mungo lunette is obtained. So the erosion of this system may have occurred in the earlier half of the Last Glacial. It would take a long time because hundreds of square kilometres of this terrace have been excavated, as Fig. 4 shows.

The sediments are all fine and very well sorted, but the stratigraphy is very variable as one would expect in a riverine environment. This applies to the Coonambidgal Formation, and to the sediments being laid down at the present time. Figure 61 shows variation in clay content from 0·50% to 68·23%, and in carbonate content from 0 to over 30% by weight. The grain size analyses were done on clay-free and carbonate-free sediments.

On Keera Station, auger holes were sunk also at Site 6 (Lybra Paddock) where many Aboriginal skeletons were excavated, and some dated by C14. They came from burials intrusive in the surface of the eroded Rufus Formation. Figure 57 shows auger 1 at the level where the skeletons were found, and auger 2 at the level

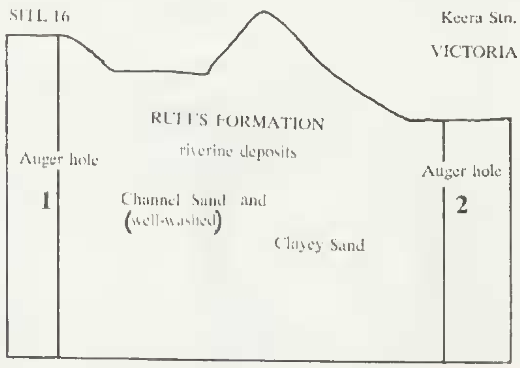


Fig. 57—Eroded Rufus Formation in Lybra Paddock, Keera Station, beside Wallpolla Creek, Vict. The site of Auger hole 2 is the 1956 floodplain of the Murray River. All sediments oxidized except 1·17 m of sediments on the above floodplain. Both auger holes were 4·8 m deep; only Auger hole 1 is shown fully. Line between auger holes = 57° magnetic.

of high floods as in 1956. This level was surveyed to a bench mark on the River Road by Sir Robert Blackwood and Mr. Gerald Douglas This showed it to be about the same height as the site of auger 1 in Brown's Paddock (Fig. 38). The logs of the auger holes are as follows:

Auger 1	On terrace.
43cm	Strong brown (7·5 YR 5/6) micaceous (as all the sands here) grading to
48cm	Reddish yellow (7·5 YR 6/6) sand with patches of earthy carbonate up to 0·5cm diameter, grading to
1·55m	Similar sediments with carbonate concretions (irregular, elongate)
1·47+m	Similar sediments with only traces of carbonate.
4·77m	Total depth.

Auger 2	On floodplain 0·82m lower.
10cm	Light gray (10 YR 7/1) silty sand
36cm	Dark brown (7·5 YR 3/2) to very dark gray (3/1) clayey sand, grading to
20cm	Grayish brown (2·5 Y 5/2) clayey sand with patch of earthy carbonate hard enough to grate an auger at times, grading slowly to
51cm	Yellowish brown (10 YR 5/6) slightly clayey sand, carbonate fading out at 84cm from surface, sharp break to
10cm	Very pale brown (10 YR 8/3) washed sand, probably a channel, sharp break to
28cm	Light gray (2·5 Y 7/3) to pale yellow (7/4) slightly clayey sand, sharp break to
10cm	Very pale brown (10 YR 7/3 washed sand, probably a channel, rapid change to
53cm	Pale yellow (2·5 Y 7/4) slightly clayey sand
10cm	Pale brown (10 YR 7/4) washed sand (channel?)
25cm	Light yellowish brown (10 YR 6/5-6) to brownish yellow sand
20cm	Mottled greenish gray (5 GY 6/1) to yellowish brown sand with clayey accretions, grading to
97cm	Yellowish brown (10 YR 5/4) washed sand
46cm	Darkish reddish brown (5 YR 2/2 and such) washed sand, sharp break to
15cm	Light gray to greenish gray (5 Y 7/1 to 5 GY 7/1) washed sand with yellowish red (5 YR 5/8) mottles, sharp break to
41+cm	Yellowish red (top 3cm) to yellowish brown (10 YR 5/4) washed sand.
4·70m	Total depth.

Grain size analyses (Fig. 56) were carried out on sediments from these two drillings as follows:

Histogram 69	Site 16, auger 1,	0–43 cm
70		43–91 cm
71		0·91–1·60 m
72		1·60–1·68 m
73		2·74–2·92 m
Histogram 74	Site 16, auger 2,	10–46 cm
75		46–66 cm
76		0·66–1·17 m
77		1·17–1·27 m
78		1·27–1·55 m
79		2·29–2·54 m
80		2·74–3·51 m
81		3·51–3·66 m
82		4·57–4·77 m

Monoman Formation

The solitary sample (CHG 55) from this formation consists of the matrix round the fossil log used for radiocarbon dating. It came from the trench sunk for an experiment on a bitumen curtain designed to prevent underflow at the proposed Chowilla Dam (Figs. 39-40). Histogram 28 (Fig. 56) shows a channel deposit with the dominant column being very coarse sand (1-2 mm).

Coonambidgal Formation

This formation includes fine-grained lagoon (or oxbow) and floodplain sediments, channel sands and channel border dunes. Histogram 29 (Fig. 56) is of alluvial on the SW. shore of Lake Wallawalla that formed the matrix of skull 61-A. It is an admixture of all grades from coarse sand to silt inclusive. There is a doubt whether these sediments should be included in the Coonabidgal Formation, but time to investigate the point has not been available.

By contrast, histogram 30 (Fig. 57) is of alluvium at the base of auger hole 1 sunk through a channel border dune. It is essentially a silt, being skewed strongly to the fine side. Histogram 31 is of the matrix of skeleton 53-A at the W. end of Lindsay Island, Berribee Station, NW. Victoria. Once again there is a typical dominance of the fine sand grade, yielding a strongly unimodal histogram.

Figure 12 shows a section of a channel border dune in the Coonambidgal Formation on Lindsay Island, Berribee Station, NW. Victoria. The logs of auger holes 1-3 are given in the geomorphology section where dunes are discussed. Auger hole 4 showed the following:

10cm	Pinkish gray (7·5 YR 6/2) well sorted sand washed from dune (surface).
36cm	Light gray (10 YR 7/1) poorly sorted sand with grain sizes coarser than in dune.
33cm	Lighter gray (N7) sand, very poorly sorted and with clay balls up to 7cm diameter. Gradual change to
8cm	Light brownish gray (2·5 Y 6/2) sand with a few streaks of light olive brown (2·5 Y 5/4).

28cm	Off-white (near N8) well-washed sand, very difficult to bring up.
61⁺cm	Same but light gray (2·5 Y 7/2).

An analysis of the N8 sand from this riverine sequence was carried out (histogram 87). The usual dominant column appears, but offset one grade to the coarse side because it is from a channel deposit. The mobile sand prevented further boring. Berribee auger hole 5 was sunk E. of the section shown in Fig. 11. The site is a red gum hollow, which is filled by present flood waters situated about 110 m SSE. of the peg at auger 1.

10cm	Dark brown (10 YR 4/3) well sorted sand. Juvenile soil formed by accumulation of humus, merging to
10cm	Grayish brown (10 YR 5/2) similar sand, merging to
10cm	Pale brown (10 YR 6/3) sand, merging to
28cm	Light gray (10 YR 7/2) well washed sand, merging to
63cm	Off-white (2·5 Y 8/2) mobile sand gradually changing to
23cm	Very pale brown (10 YR 7/3) mobile sand, gradually changing to
1·22m	Light yellow brown (10 YR 6/4) mobile sand
15cm	Pale brown (10 YR 6/3) sand, and light-gray (5 Y 7/1 to 5 GY 7/1) clayey fine sand merging to
36cm	Very pale brown (10 YR 7/3) sand
13cm	Same with gray clayey fine sand as above
8cm	Pale brown (10 YR 6/3) sand without gley
8cm	Same with patches of yellow (10 YR 7/6)
13cm	Brown (10 YR 5/3) clayey sand
25cm	Same with gray clayey fine sand as above.
36cm	Brown sand without gley.
33⁺cm	Brown with mottles of gray and strong brown (7·5 YR 5/6) concentrating in places to dark reddish brown (5 YR 3/2) sand, but the latter disappears 15cm from the bottom, leaving brown and gray sand only.
4.53m	Total depth.

An analysis was carried out of a sample 71-74 cm from the surface (off-white mobile sand), and the result appears in histogram 88 which is bimodal. Dominance moved back to the fine sand grade. Sand is blown from the channels to form the dunes, and sand from the dunes is washed back into the channels. The grade of sediments dominating the channel deposits is limited by its dynamics. The sands are well sorted (So = 1·46) as usual.

Nulla Nulla Sand

This is the lower member of the Lake Victoria Sand (lunette). Fig. 58 presents three histograms characterized by a dominant column of fine sand—the typical grade in this river system of low dynamics. The sediments are finer than are usually found in dunes, but this is what the river transport provided. The light weight of the sand grains, the limited supply brought in by the river, and the persistent seasonal W. winds are no doubt the chief contributory factors to the subhorizontal position of most of these sands. Ample winds moving a light sand of limited quantity kept the dune in a state of almost constant blowout.

Histogram 89 (Fig. 58) is from Talgarry Station just S. of the border fence with Nulla Station, below our bench mark 1 (CHG SS 110). Histogram 90 is from a clayey horizon (CHG 98) with badlands erosion on Nulla Station (N14/15). Histogram 91 (Fig. 58) is for the matrix of a fossil marsupial from Talgarry Station, and is dominated by the very fine sand grade.

Talgarry Sand

This is the upper member of the Lake Victoria Sand (lunette). Histograms 92 and 93 (Fig. 61) show two types of sediment found in the Talgarry Sand that have parallels in the underlying Nulla Nulla Sand.

Sediments in relation to Facies. The sorting coefficients of the sand fractions relative to facies

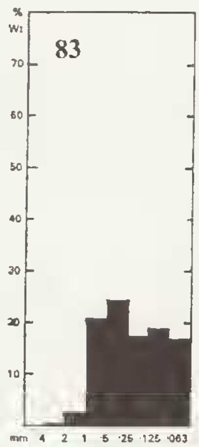


Fig. 58—Histogram of grain size analysis of Monoman Formation sediments from the cut-off trench at the Chowilla Dam location (Site 1). Sample CHG 55.

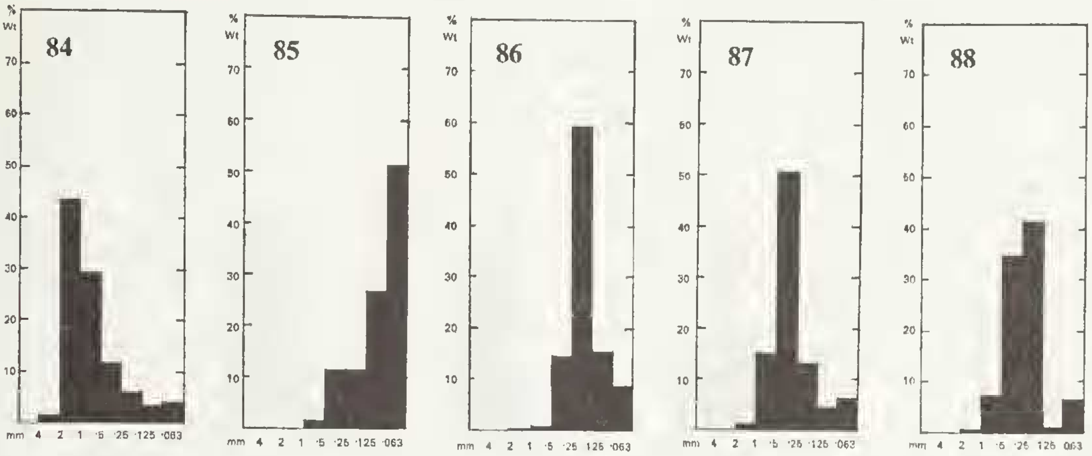


Fig. 59—Histograms 84-88 of grain size analyses of Coonambidgal Formation sediments. 84 = Matrix of Aboriginal skeleton 61A from SW. side of Lake Wallawalla (Figs. 14-15). Sample CHGSS 118. This is doubtfully referred to this Formation. 85 = Mottled clay from bottom of auger hole 1, c. 3 km SSW. of Berribee Stn. homestead under Woorinen Formation dune. This is almost certainly not Coonambidgal but the formation to which it belongs has not yet been determined. Sample CHGSS 31. 86 = Matrix of Skeleton 53A, W. end of Lindsay Island (Site 19). Coonambidgal channel border dune. Sample CHA 95. 87 = Off-white (2·5Y N/8) sand from auger hole 4, Lindsay Is., Berribee Stn., N.S.W. (Fig. 12) 0·86 — 1·14 m. Sample CHGSS 39, 88 = Same site, auger hole 5 sunk on E. side of channel border dune (Fig. 12) 0·66 — 0·74 m. Sample CHGSS 40.

are as follows (the number of So determinations is given in brackets):

1. *Riverine floodplain*
   - Parilla Sand (2) 1·3–1·17
   - Rufus Formation (52) 1·20–2·55 (omitting So 4·3)
   - Coonambidgal Formation (5) 1·22–1·46 (omitting So 2·10 which doubtfully belongs to the formation)
2. *Riverine channel*
   - Moorna Formation (5) 1·25–1·54
   - Chowilla Sand (6) 1·14–1·68
   - Blanchetown Clay, sandy facies (1) 1·27
3. *Lacustrine*
   - Blanchetown Clay (1)
4. *Dune*
   - Woorinen Formation (9) 1·29–1·52
   - Nulla Nulla Sand (3) 1·53–1·60
   - Talgarry Sand (2) 1·44–1·77

The whole series is remarkably fine which can be attributed to long transport and no fresh sediments brought in during the long flows across dry country. The degree of sorting is remarkable. This can be attributed to the low dynamics cutting out the larger fractions, and the long transport ever improving the sorting. There is an enormous range in the percentages of carbonate and clay. Accumulation of carbonate is largely a pedogenic function. The variations in the clay content of riverine alluvia are such as are to be expected. In this semi-arid country, windblown fine sediments have been added later to waterlaid sediments.

Denudation. The mean denudation rate is remarkably low. Langbein and Schumm (1958) have studied the quantitative relationship between sediment load and annual precipitation, concluding that maximal sediment yield occurs in areas of 25-30 cm rainfall, to which our study region belongs. The authors measured solid load only. Ahnert (1970) points out that seasonal distribution of rainfall is important, and it certainly is in our Project area. Ahnert deals also with the significant factor of relief. 'The mean denudation rate in mid-latitude river basins is directly proportional to mean basin relief'. The very flat Murray Basin has minimal denudation. Many relict features such as the

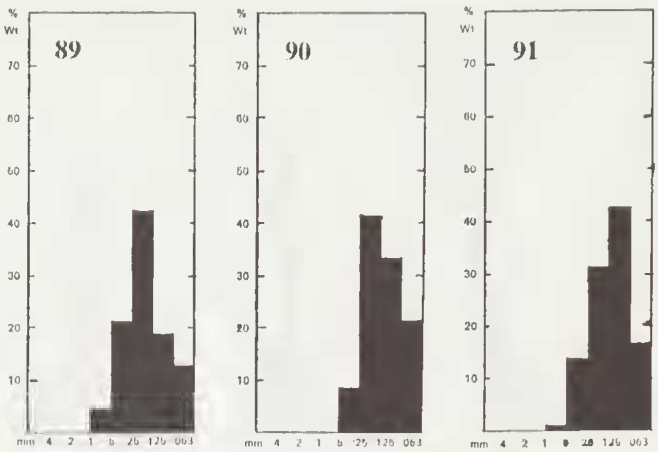


Fig. 60—Histograms 89-91 of grain size analyses of sediments from the Nulla Nulla Sand member of the Lake Victoria Sand Formation (Figs. 42-45). 89 = Nulla Nulla Sand from below bench mark 1 on S. (Talgarry Stn.) side of the boundary fence (Fig. 16). Sample CHGSS 110, 90 = Clayey sand with herringbone erosion, Gulch N14 (Fig. 16) interpreted as a fossil claypan. Sample CHG 98. 91 = Matrix of marsupial fossil from Nulla Nulla Sand, Lake Victoria Lunette, Talgarry Stn. Sample CHGSS 129.

Pleistocene E-W. dune system persist little altered. North of the Murray River and West of the Darling River, the terrain consists of the Pliocene/Pleistocene Blanchetown Clay with discontinuous surficial sand. A 'steady state relief' has been established.

Palaeontology

As most of the outcropping formations were deposited under semi-arid conditions, plant fossils are not common. The highly oxidizing environment (see Maher, this *Memoir* for climatology) is inimical to the preservation of plants. The ?water plants in the Blanchetown Clay at 'Warrakoo' have already been mentioned, and the fossil trees at the Chowilla Dam site. Blackburn (1971) has recorded a podocarp root from Telangatuk East, further S. in Victoria. Gill and Bethune (1967) obtained pieces of wood from a bore at Narrandera that dated 32,000 ± 1,200 yr and > 33,000 yr. Wood was obtained by Mr Bethune in a bore at Raak, Victoria. At Mildura wood from a depth of 10·7 m near the Psyche Bend pumping station dated 5,400 yr (NZ-196). Churchill (this *Memoir*) has recorded pollens and spores. The amount was small but further work in this field is projected because this flora marks the incoming of the semi-aridity. Near where the sample was collected for Dr Churchill, a thicker section was later revealed by removal of slope wash. This outcrop presented 1 m of black sediments, providing scope for serial study. The cliffs of Salt Creek at the S. end consist of Chowilla Sand with slump material forming a talus slope at the base that probably conceals Parilla Sand. The palynological site is where the Blanchetown Clay begins to lens in within the Chowilla Sand. The deposit is that of a lake shore.

The Animalia are better represented among the fossils. Marshall's paper in this *Memoir* describes the vertebrates, which can be compared with those from Lake Tandou in the same region (Merrilees, this *Memoir*).

The formations described have the following fossils:

1. *Bookpurnong Formation,* Cheltenhamian marine fossils of shallow water facies.
2. *Parilla Sand.* Samples of these floodplain sediments yielded no spores or other fossils, but as the beds are unoxidized and carbona-

ceous in some places, further search may find them.

3. *Moorna Formation.* Fish (including *Neoceratodus*), tortoise, ratite bird (egg shell), marsupials and ostracods.

4. *Blanchetown Clay* (and its limestone members). Fish, marsupials, worms (casts), molluscs and ostracods (McKenzie and Gill 1968).

5. *Chowilla Sand.* Fish, tortoise, marsupials, crustaceans (gastroliths) and ostracods. At Bone Gulch on Moorna Station, in the Chowilla Sand below the Blanchetown Clay are structures interpreted as burrows (Pl. 7).

6. *Rufus Formation.* Fish, ratite bird (egg shell), marsupials and rats. In Browns Paddock, Keera Station (Fig. 38), are 'fossil' formicaria. Noting a circular patch of carbonate rising 10 cm above the surface of the carbonate-free red sand hardpan, I sank an auger to investigate the anomaly, and found that a carbonate rich zone continued to a depth of over 50 cm. The structure was then excavated by spade, and recognized by K. N. G. Simpson as the former nest of a large ant such as the Bulldog Ant (*Myrmecobius*). The galleries attained a maximal diameter of 1·3 cm. The carbonate at the surface had been carried up by the ants from the B horizon of the soil, including pieces up to 1·2 cm long. We found a small species of ant no larger than 10 mm in length occupying the galleries in the top 2-5 cm of the abandoned formicarium.

7. *Nulla Nulla Sand.* Molluscs, reptiles, marsupials (including extinct genera and species), rats and man (skeletons and middens).

8. *Talgarry Sand.* Same range of fossils, but all living species.

9. *Monoman Formation.* Fossil wood and marsupials.

10. *Coonambidgal Formation.* Aboriginal burials and middens.

Aboriginal bones and middens along with some marsupial bones were found in the hamada on the W. side of Lake Victoria. As our investigation was only at reconnaissance level, there are probably many more palaeontological sites to be found. Certainly more fossils will come from a systematic treatment of the sites discovered.

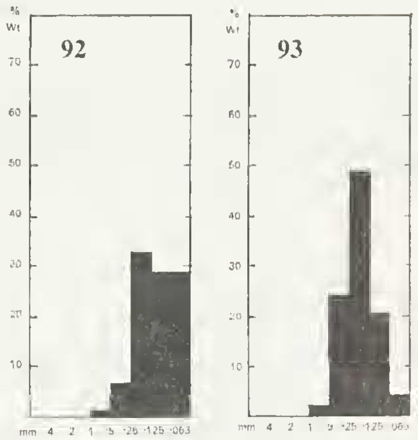


Fig. 61—Histograms 92-93 of grain size analysis of Talgarry Sand member of the Lake Victoria Sand formation.
92 ± Sample CHGGS 112 at BM 1, Talgarry Stn. just S. of boundary fence shown in (Fig. 16. 93 = Matrix of Skeleton A from Gulch S1 (Fig. 16), Talgarry Stn., E. side of Lake Victoria, N.S.W. Sample CHG 309.

Following very heavy rain, bones in the Nulla Nulla Sand can achieve consistency rather like that of cheese, and can be readily cut with a knife. On drying out, they become hard again. While plastic they can be deformed. A few workers in other countries have noted (pers. comm.) the same or a similar phenomenon, but no study of it has been discovered in the literature.

Palaeoclimatology

Je m'en vais chercher un grand peutêtre.

Rabelais

This subject is as difficult as it is important. For the former reason many avoid it. Adequate treatment involves great masses of detail plus unifying ideas. However, if all authors provided such palaeoclimatic data as they have, and passed on any ideas that occurred to them, we would be much further advanced in this large field of learning. The palaeoclimatology of the study area is approached in this way.

Terrestrial palaeoclimatology is more difficult than marine palaeoclimatology, because more variables exist. Local microclimates are pre-

Figure 62

Sedimentology

The Sorting Coefficient (So) is of sediment without carbonate or clay, unless otherwise stated. Perfect sorting = 1, 2.5 = well sorted, 3 = normally sorted, and 4.5 = poorly sorted (Trask.)

PARILLA SAND

Histogram	Sample	% Carbonate	% Clay	So	
1	78	0	2.92	1.30	Floodplain
2	115	0	13.86	1.17	

MOORNA FORMATION

Histogram	Sample	% Carbonate	% Clay	So	
3	113	2.18	27.65	1.54	
4	111[1]	17.9	3.42	1.49	Dolomite removed from sand grains
5	111[2]	-	-	1.36	Untreated sample; channel facies
6	118	12.26	0.56	1.25	
7	94	0	19.62		
8	108	0	2.88	1.45	

CHOWILLA SAND

Histogram	Sample	% Carbonate	% Clay	So	
9	38a	0	0.85	1.23	Channel facies
10	77	0	1.98	1.14	
11	109	3.66	11.87	1.48	
12	117	3.20	0.51	1.57	
13	41				Early tests; washings not weighed
14	43				
15	116	0	4.39	1.52	
16	114	0	18.16	1.68	

BLANCHETOWN CLAY

Histogram	Sample	% Carbonate	% Clay	So	
17	42	0	68		Normal facies; more clay sometimes
18	151a	21.95	18.35	1.27	Sandy facies with Corbicula

WOORINEN FORMATION

Histogram	Sample	% Carbonate	% Clay	So	
19	32	0	5.40	1.34	Dune facies
20	33	7.02	7.72	1.30	
21	34	3.38	13.01	1.34	
22	35[1]	10.98	0.88	1.29	
23	35[2]			1.29	Repeat
24	36	3.29	11.9	1.30	
25	37	11.87	5.70	1.52	
26	38b	0	57.92	1.31	Floodplain or lake of underlying terrain
27	118	30.14	2.34	1.37	

RUFUS ALLUVIUM

Histogram	Sample	% Carbonate	% Clay	So	
28	74	13.73	8.01	1.59	Floodplain facies Outlier 1, Auger 1
29	75	14.33	8.23	1.58	
30	76	10.71	26.15	1.52	
31	77	7.51	14.51	1.48	
32	78	5.27	10.77	1.37	
33	79	3.33	6.80	1.36	
34	80	5.16	4.40	1.50	
35	81	2.66	15.44	1.37	
36	82	2.07	42.08	1.37	
37	83	1.57	68.23	1.65	
38	84	0	22.97	1.46	
39	85	0	18.61	1.69	Outlier 1, Auger 2
40	86	7.14	20.95	1.60	
41	87	5.30	15.67	1.54	
42	88	4.37	15.86	1.55	
43	89	2.03	8.34	1.57	
44	91	0	8.47	1.57	
45	100	0	22.47	1.40	Outlier 1, Auger 3
46	101	0	4.62	1.20	
47	92	0	2.93	1.57	Outlier 1, Auger 4
48	93	5.93	54.28	1.54	
49	94	8.98	25.16	1.31	
50	95	0	5.59	1.29	
51	96	4.65	19.63	1.56	
52	97	0	8.88	1.33	
53	98	29.57	14.75		
54	102	6.82	59.98	1.72	Outlier 2, Auger 1
55	104	3.40	18.37	1.28	
56	105	0.61	2.38	1.29	
57	106	18.97	0.50	1.37	
58	107	30.09	9.62	1.51	
59	400	4.40	2.26		Site 1, Auger 1
60	401	1.6	12.9		
61	402	12.7	16.0	1.78	
62	403	0	63.9	2.55	
63	404	0	47.5	4.3	
64	405	0	18.6	1.61	Site 1, Auger 4
65	406	16.8	35.7	2.00	
66	407	5.3	39.08	2.04	
67	408	0	42.07	1.57	
68	409	0.93	3.80	1.28	
69	410	0	12.0	1.41	Site 1, Auger 1
70	411	0	6.4	1.41	
71	412	0	4.98	1.43	
72	413	0	4.0	1.45	
73	414	0	16.2	1.46	
74	415	0	69.2	1.41	Site 6, Auger 2
75	416	9.69	12.5	2.22	

Histogram	Sample	% Carbonate	% Clay	So	
76	417	2.11	2.62	1.52	
77	418	0	12.6	1.43	
78	419	0	18.6	1.50	
79	420	0	4.76	1.42	
80	421	0	3.05	1.33	
81	422	0	1.60	1.33	
82	423	0	2.25	1.06	
		MONOMAN FORMATION			
83	55				
		COONAMBIDGAL FORMATION			
84	215	18.80	9.98	2.10	Lake Wallawalla, doubtfully referred this formation
85	31	0	25.80	1.22	
86	95	1.68	15.5	1.34	
87	39	0	11.61	1.43	
88	40	0	3.70	1.46	
		NULLA SAND			
89	110	1.09	4.18	1.53	
90	98	7.42	6.53	1.60	
91	129	2.37	0.12	1.56	
		TALGARRY SAND			
92	309	0	2.30	1.44	
93	112	0	3.48	1.77	

valent. Living organisms have inbuilt adaptive mechanisms so that within limits they change with the changing environment. Climacteric events are sometimes of sufficient magnitude to leave a record of these atypical happenings, diverting attention from the more significant persisting characters of the terrain. The solution to this problem in our investigation was to consider evidence that was consistent over large areas of country. For example, the E-W. longitudinal dune system, once mobile but now immobile as a system, covers some 200,000 km². This extensive regional change in the status of sediments sensitive to effective rainfall and wind regime is a matter of prime palaeoclimatic importance. Another example is that beneath this semi-arid terrain, clogged with surficial carbonates and sulphates (proof of low humidity and little leaching), there lies a fossil lateritic profile (proof of high humidity and very deep leaching). Smaller changes of climate are harder to discern, but they are best deciphered in marginal areas where maximal change has occurred. Many misinterpretations of past climates have been due to lack of an adequate chronology. In the present study, the order of events is unequivocal, and progress has been made with chronometric measurements, but a great deal remains to be done. Thus, while the change from humidity to semi-aridity can be located in the stratigraphic succession, the time cannot be defined with any precision.

In SE. Australia, the palaeoclimatic history prior to the period represented by the rocks exposed in the study area may be generalized as follows:

1. *Cretaceous Frigid Supercontinental Climate*

It is widely held that Australia was attached to the Antarctic continent in the Cretaceous (Smith and Hallam 1970), that the south pole was nearby (Wellman *et al.* 1969), but higher temperature zones existed to the NW. (Gill 1972d and references), and that Australia drifted away from Antarctica in the Upper Cretaceous to Eocene (Veevers *et al.* 1971, Jones 1971). The high percentage of felspar ($\sim$ 40%) in the extensive Lower Cretaceous rocks of Victoria has long been a puzzle, but if the climate were frigid, this can be understood. Solitary pebbles of plutonic and metamorphic rocks and patches of gravel unassociated with current bedding, and not streamed out in lenses, may be drop pebbles from floating ice. In 1949 I observed with Mr A. A. Baker and others a cliff in the Cape Patterson area in S. Gippsland, E. Victoria, a large mass of laminated fine arkose about 4·5 m long with sharp broken edges, and fragments 'floating' in the surrounding matrix. This massive piece of rock was certainly not transported by water. It is completely out of character with the surrounding sediments and their dynamics; its edges are uneroded. At the time, the only solution I could conceive was that it fell from a cliff, but this could not be accepted by reason of the stratigraphy shown in the wide shore platforms and high cliffs. To explain this as a rock mass dropped from melting ice into the sediments on the floor of a lake explains all the factors observed. More recently, varves have been found at Koonwarra, with fossils that appear to represent winterkill (Waldman 1971).

2. *Mid-Tertiary Subtropical or Tropical Rainforest Climate*

The marine biota is a warm one, while on land there were large reptiles and thick rainforests that formed extensive brown coals (Gill 1961a-b, Duigan 1966, Dawson and Sneddon 1969, Dawson 1970). At first, the climate appears to have been without seasonal change in humidity, so that deep leaching with kaolinization occurred to 60 m. These conditions created the *Nunawading Terrain* (Gill 1964) and were succeeded by a seasonal monsoonal type climate that yielded laterite. It is significant that at that time (Pliocene, Gill 1971) laterite developed both land- and seaward of the Dividing Range. The type section of Cheltenhamian marine sediments on the coast at Melbourne is lateritized, as also are sediments overlying the Cheltenhamian fossil bed at Tareena Station on the Murray River. In some places, the Nunawading Terrain is overlain by later sediments that are lateritized.

If at this time, SE. Australia was drifting N. from the frigid zone towards its present temperate zone position, the tropical or subtropical climate must have been due to a change in world climate that widened the tropical belt. On what is known of world climates, this could well be.

Axelrod and Bailey (1969) have suggested that climatic change in the Miocene could have been effected simply by transgressive seas reducing extremes, 'and hence biota (both marine and non-marine) would assume a somewhat warmer aspect under the more equable conditions'. However, more than a change in equability is involved in SE. Australia as is proved by gross change in soil types, by the presence of certain stenothermal genera, and such major shifts. The change from the cold climate in early Tertiary to more or less tropical conditions in the mid-Tertiary, followed by a major change in fauna and flora with cooling and drying climate in the upper Tertiary is more than can be explained by an increase in equability. The change took place both N. and S. of the Dividing Range. The sea exercises little control of the climate N. of the Range. It should be noted that Australia is naturally more equable in climate than most continents (e.g. Europe, Asia and N. America) because it is set in a wide expanse of ocean and possesses no land link with the Antarctic. In addition, its mountains are exceptionally low, for Australia is the flattest continent.

The deep kaolinization of the Nunawading Terrain is apparent in the solid rock areas of Victoria, New South Wales and South Australia, but not of course in the rapidly sinking Murray Basin. Moreover, the study area was invaded by the sea during the mid-Tertiary.

Following the above two palaeoclimates, there were three phases that left their impress on the terrain by significantly different types of paleosols, viz.

(a) A lateritic profile that accumulated nonmagnetic iron oxide.
(b) A paleosol that accumulated silica in sands and common opal in clays. Such a soil infers a different pH from lateritizing conditions.
(c) A series of pedocals that accumulated earthy carbonates to crystalline nodules, the latter typically with an amorphous centre but concentric laminae on the outside.

3. *Monsoonal type climate*

This develops rainforest, but is characterized by alternating wet and dry seasons. Heavy rainfall drenches the earth with copious warm waters that leach it deeply, causing kaolinization. This is followed by a dry season when the water table falls and the air enters, oxidizing the zone above the table. Mottles of iron oxide form, and if the process continues long enough, the part of the mottled zone always exposed to oxidation becomes fully oxidized, resulting in the ironstone horizon which is 'laterite' in the strictest sense.

The lateritic profile is so deep and the leaching so intense that it reflects a climate which is the converse of the present semi-arid conditions, wherein soluble carbonates remain at the surface. The next climate represents the transition between these extremes.

4. *Monsoon/Arid Transition Climate*

Whether this is an adequate characterization of this climate, there is not enough evidence to say, but it is established that a climate causing deep leaching changed to a desertic one. The present climate is semi-arid but when the EW. dunes were active, the climate would be classifiable as arid. This transition is reflected in the sediments, the fossils and the soils. Tectonic movements about this time appear to have further uplifted the Dividing Range, which event must also have contributed to change of climate in the areas concerned. However, the climatic change extends far beyond the influence of the Dividing Range (e.g. Lowry 1970, Twidale 1972), so factors other than uplift are involved.

When Australian Oil and Gas sank Lake Victoria No. 1 well, they met late Miocene marine Bookpurnong Beds at 308 feet (94 m). Above that was a sequence of gypseous sands (arid/semi-arid) passing into pyritic sands (pluvial) with carbonized wood fragments and fish bones. The passage is from alkaline to acidic sediments.

The lowest formation outcropping along the Murray River in the study area is Parilla Sand which is a gray clayey fine sand. It is riverine, and its carbon content (high in places) contrasts with the low carbon content of the Coonambidgal Formation which was deposited by the same river. It is succeeded by the well washed oxidized Chowilla Sand (channel deposit) which interdigitates freely with the Blanchetown Clay. For the present purpose the latter two formations can be treated as one, and then the successively higher levels will represent successively younger zones. The Blanchetown Clay is thickest in the Nampoo Station cliffs, and it is at the base of the exposure that evidence of the incoming drier climate is first met. By tracing the river cliffs to the NW., the gradual replacement of Blanchetown Clay by Chowilla Sand can be followed through Cal Lal to the Kulcurna Station homestead, where Blanchetown Clay is mising. Nearby at the S. end of Salt Creek the formation lenses in again well up in the Chowilla Sand section, i.e. at what is interpreted to be a later horizon. There the present semi-arid flora has been recognized by Churchill (this *Memoir*).

At Sharp Point on the Nampoo cliffs (Fig. 26), three types of evidence combine to indicate the increasing dryness of the climate:

(a) *Deposition of dolomite* (cf. Zenger 1972). As indicated elsewhere in this paper, it is considered that this rock was a product of warm temperatures, low rainfall and high evaporation resulting in saline waters. Such dolomite is precipitated in the Coorong in S. Australia at the present time. The two dolomite layers show repetition of the sensitive conditions necessary for deposition. Deposits also occur at Triple Swamp (Fig. 24) and elsewhere low in the Blanchetown Clay/Chowilla Sand complex. The top of this complex is at plateau level. No dolomite has been found in the top three quarters of the complex.

(b) *Drying up of Lake*. The Blanchetown Clay is a lacustrine deposit. To spread channel sands (Chowilla Sand) across a lake bed (Blanchetown Clay) is evidence of shallowing, as also is the deposition of the dolomite. The lake dried up eventually as is proved by the formation of a soil and development of rhizomorphs. This soil accumulated silica, which at Sharp Point is in the form of common opal, but at Cal Lal is a cement forming silicified sandstone. In places, e.g. N. Salt Creek, silcrete occurs. I followed opal deposited in clay to where in the sandy facies nearby it became silicified sand to silcrete.

Deposition of opal appears to be controlled by impedance of drainage, and so presumably the formation of a gel. The formation of opal has been attributed to different geological periods, including the time of development of the lateritic profile. Because of basin sinking, the succession is here extended, making it easier to distinguish successive geologic events. In this instance, it can be proved that the opal is younger than the laterite. The upper opal layer at Sharp Point is a cemented breccia in places, suggesting some kind of dessication followed by further deposition.

This paleosol is very widespread. It is the Karoonda Surface or Terrain of Firman (1967). For example, Kosciusko Epoch sediments overlying kaolinized granitic rocks at Home Rule, N.S.W., are silicified, and this may be referable to the same climatic phase. Silicification has been noted near the surface in many places in the Mallee area of N. Victoria. It seems a good thing to give the same name to the fossil terrain and the paleosol that occurred on it. In this case, the latter could be called the Karoonda Pedoderm. No application has been made for the recognition of this as a stratigraphic name.

The paleosol is often eroded, as can be seen (for example) by following the silcrete layer along the Merbein Cliffs (Fig. 36). It is absent in other places, although features such as mottling of the Blanchetown Clay (e.g. in the S. bank of the Murray Cliff at Yelta) may be an expression of it.

In W. Victoria a fossiliferous site has been described which records the changeover period from the humid climate with a conifer/*Nothofagus* flora to the present dry *Eucalyptus/Acacia* flora (Gill 1957). A vertebrate fauna has been described from the same horizon (Turnbull and Lundelius 1970). A basalt flow 4·35 m.y. old has sealed off the deposit. Fluviatile sediments under thick basalts at Smeaton are referable to this same changeover period (Gill, in prep.). Dr Ian McDougall kindly undertook to date for me a sample from one of the overlying basalt flows with the result of 2·11 m.y. (Aziz-ur-Rahman and McDougall 1972). The changeover time appears to have been of considerable duration, and so is listed here as a separate palaeoclimatic phase.

5. *Arid/Semi-arid Climate*

All formations later than the Chowilla Sand/Blanchetown Clay complex have carbonate associated with them, except for those forming the present river floodplain. Polygenetic carbonate soils characterize the surface of the Blanchetown Clay forming the flat plateau country. At least three cycles are involved, as represented by:

(a) Crystalline calcite nodules included in a younger generation of such nodules.
(b) The younger generation of these hard nodules which are ~ 28,000 years old.
(c) The still younger accumulation of earthy carbonate ~ 16,000 years old.

In the dunefields, corresponding periods of terrain stability and instability can be traced over extensive areas. In the erosion amphitheatres on the W. side of Lake Victoria there are matching periods of erosion and deposition, judging by the few radiocarbon dates available. There are indications also of Holocene oscillations, finishing with the 'indurated layer' (Fig. 46) currently being deposited.

Mid-Holocene Thermal Maximum. Such is described from many parts of the world, but many Australian workers have claimed it does not occur here. This is too much to claim as so little work has been done on palaeoclimatology. However, one can describe the evidence one finds, and offer an interpretation of it.

Before C14 and U/Th dating, evidence of more than one drier period was telescoped into a single 'Arid Period' believed to be of mid-Holocene age. In 1955 the author wrote a paper placing the term 'Arid Period' (as applied to the mid-Holocene) in inverted commas and stating it was a misnomer. It was pointed out that the basic climatic change is one of mean temperature, that this does not necessarily mean change in humidity in a particular direction, and therefore the term 'Arid Period' should not be used. In spite of this, numerous authors have referred to this paper as indicating my belief in the mid-Holocene 'Arid Period', and it is hoped that this note will encourage the accurate reading of what was written. Nevertheless, I do think that in Australia there was a small but definite mid-Holocene climatic oscillation characterized by a small rise in temperature such as has been described from many parts of the world. In the study area the following evidence has been noted:

1. A disconformity between the Monoman and Coonambidgal formations at the Chowilla Dam site is marked by a layer of fossil stumps and logs that range in age from 4,080 to 7,200 years. The sediments below are oxidized.

2. A disconformity exists in the large lunette on the E. side of Lake Victoria between the Nulla Nulla Sand Member and the Talgarry Sand Member. Aboriginal midden shells in the paleosol marking the disconformity dated 6,360 years. At the end of this period, gulches were excavated by wind erosion then later infilled with Talgarry Sand.
3. On the E. side of Dolomite Gulch at Triple Swamp on Moorna Station an Aboriginal midden was found between the A and B horizons of the soil. The original A horizon must therefore have been eroded away and later reconstituted. The date of the midden (7,210 yr) is within the erosion interval. At Port Campbell in Western Victoria a winnowing of the A horizon of a humus podsol was proved, and the interval as represented by charcoal samples was 4,830 to 5,700 years. Limits on the period of time involved are placed by other samples which dated 7,380 and 3,880 years respectively (Gill 1965). Along the coast of Victoria are emerged marine shell beds with evidence of slight warming that give dates from 3,980 to 7,040 years (Gill and Hopley 1972).
4. In N. Victoria a ridge of granite (Terricks Range) stands up through the sediments of the Murray Basin. At Mitiamo, the excavation of the clayey sand on a pediment revealed an Aboriginal skeleton at the base that dated 5,540 yr. B.P. so this was presumably in a time of deflation when the pediment was swept almost bare (Gill 1967).
5. The most characteristic mammal of this semi-arid country is the Red Kangaroo *Megaleia rufa*. It does not occur now S. of the Dividing Range in Victoria. However, in the mid-Holocene it was in S. Victoria. Mr E. H. Wilkinson and Dr P. Lang found it at the outlet of Lake Gnarpurt in Western Victoria. The skeleton was in fine lacustrine sediments with *Coxiella* shells, which dated 4,550 years (Gill 1971b). These thin-shelled brackish-water gasteropods give a date on the young side where check has been possible, so the Red Kangaroo may be a little older, but still mid-Holocene.

Early records and surface bones show that *Bettongia leseur* was also characteristic of the semi-arid fauna before the introduction of European cats and dogs. Bones of this species occur at Bushfield in W. Victoria, where they underlie the Tower Hill Tuff dated 7,300 years B.P. (Gill 1963, 1972c, Wakefield 1972).

6. *The Last 30,000 Years*

Radiocarbon dating provides reasonable chronologic control for this period. Insufficient is known to make a proper palaeoclimatic chart, and too few dates have been obtained. The carbonate dates in the upper part of the radiocarbon range need to be treated with reserve until they are better understood. However, the following table is the picture that appears on present evidence, and it is presented as a stimulus to further thought. Some of the contemporary events S. of the Dividing Range are also given.

Order of C14 Age	*Events*
0–4,000 years B.P.	Emplacement of youngest colluvial fans, dunes, and floodplain deposits (Coonambidgal Formation, Dunedin Park Sand Member, etc). Formation of youngest carbonate soils, and youngest Aboriginal middens and ovens. Modern erosion (0-150 yr.) Probably two phases in this period.
4,000–6,500	Terrain instability in study area. In Lake Victoria lunette, soil (with midden dated 6,360 y.) cut by gulches and covered by Talgarry Sand Member. Extant vertebrate fauna with minor changes. No surficial Aboriginal sites of this age found, but burials of this period prove their presence.

Disconformity between Coonambidgal Formation and Monoman Formation at Chowilla Dam site marked by fossil trees, and oxidation of underlying sediments.
Pediment with Aboriginal skeleton buried at Mitiamo, N. Victoria.
Deposition in Devon Downs site further down Murray R.
Deposition of pedogenic carbonate N. and S. of Dividing Range (not presently so deposited S. of Range).
Red Kangaroo migrated S. of Dividing Range.
Deflation of topsoil at Port Campbell, S. of Range, where surface presently well stabilized.
Higher sea level on coast of Victoria shown by emerged marine platforms, shellbeds, and other shoreline structures.

6,500–9,000 Terrain stability.
This period is ill-defined, but before the above sand movements began, a red soil was formed over most if not all of the large Lake Victoria lunette. Below this soil, high in the Nulla Nulla Sand were bones of an extinct kangaroo that dated 9,610 yr.

9,000–15,500 Terrain instability.
Deposition of upper part of Nulla Nulla Sand Member in the Lake Victoria lunette.
Deposition of the uppermost member of the E-W. dune system.
Extinct vertebrates.

15,500–17,500 Terrain stability.
Paleosol formed in Lake Victoria lunette, and in E-W. dune system (Woorinen Formation).
Paleosol in clay (parna) dune on E. side of Lake Corangamite, S. of Dividing Range.

17,500–27,500 Terrain instability.
Penultimate member of E-W. dune system emplaced.
Deposition of lower part of Nulla Nulla Sand in Lake Victoria lunette.
Extinct marsupials present.
In some places a paleosol intervenes at 24,000 yr. (e.g. Nyah, W.).

27,500–30,000 Terrain stability.
Paleosols formed in E-W. dune system.
Probably Lake Victoria lunette initiated in this period.
Pedogenic calcite nodules with laminated cortices below E-W. dune-field and on general terrain of Blanchetown Clay. At least two generations are involved, the second extending back beyond the range of radiocarbon dating.
S. of Dividing Range, shells from high level beach of Lake Corangamite dated 28,240 yr (Gill 1971b).

The information available so far indicates alternating periods of terrain stability and instability. These are judged to be a function of significant variations in dryness, and probably also in windiness (Wilson and Hendy 1971). In the more humid country S. of the Dividing Range there is a similar pattern but, as may be expected, the time limits of the periods are not exactly the same.

Ecology

Two ecologic zones characterize this country (1) the flatland of the general terrain, and (2) the flatland of the wide floodplain incised 37 m therein.

1. In the study area, the general terrain is markedly different N. and S. of the Murray River.
   (a) To the S. the country is essentially sandy due to the dunes and sand

spreads of the Woorinen Formation. This is the Millewa Land System of Rowan and Downes (1963). Mallee scrub is the dominant vegetation.

(b) To the N. of the river the country is essentially clayey (due to the Blanchetown Clay substrate) with only a veneer of sand. Saltbush is the dominant vegetation.

The sandy facies to the S. of the Murray R. is an expression of fluviatile activity later modified by wind action. The clayey substrate to the N. of the river is an expression of lacustrine activity. The River Murray has followed the interface between these blocks of different sediments. The sands are much easier to erode than the clays. These generalizations provide a basic understanding of the country, but the actual situation is of course much more complex. The hypothesis put forward here for the course of the Murray requires testing by more detailed investigation. A tectonic factor is also likely.

2. The floodplain has been divided by Rowan and Downes (1963) into two zones:
   (a) Ned's Corner Land System consisting of higher ground (including the Rufus Formation). The dominant vegetation is saltbush.
   (b) Lindsay Island Land System, which is Holocene floodplain (Coonambidgal Formation) with channel border dunes and such. The dominant vegetation is *Eucalyptus camaldulensis* lining the streams, with *E. largiflorens* on the floodplains behind.

Information on the present fauna is given by Simpson (this *Memoir*) and that of the past by Marshall and Merrilees (this *Memoir*) plus the paleontology section of this paper. An investigation of the operation of the ecosystems involved is needed.

During the drought of 1967-8 many sheep died of malnutrition. Although in good seasons there is only minor competition between sheep and kangaroos, it becomes direct in time of drought. Graziers culled the kangaroo population, but the latter were still numerous, as they came from inland to within watering distance of the river. As soon as the rains came, the kangaroos disappeared inland. During the drought some birds that are normally further N. also came S. Thus at such a time there is a temporary population zone shift.

The Aboriginals were oriented to the river in a similar way, and went into the hinterland when the rains formed pools and re-charged small reservoirs in bodies of sand underlain by clay. Their mussel middens, implements, and fireplaces provide the evidence. As mussels occur only in the rivers and lakes, they must have been carried inland. They were noted on Talgarry Station nine miles E. of Lake Victoria, the nearest source.

Evolution of Ecosystem

When the Lower Cretaceous epicontinental seas withdrew, Australia changed from a pattern of islands to its present island continent status. The river systems ancestral to the present ones were then established. At that time SE. Australia had a subantarctic climate which graded to a subtropical one in the N. (Gill 1972d). This gradually changed until in mid-Tertiary a subtropical climate with extensive rainforests (that formed brown coals in grabens, and deep-leached soil profiles on horsts) existed in this area. From then till now there has been an overall drop in temperature and humidity. The incoming of the present aridity to the study area is described elsewhere in this paper. The time was ~ 2 m.y. ago. In that period the fauna in and around the river adjusted to a regime where the river could be anything from a string of salty pools in drought to a flood reaching tens of kilometres wide. Thus great extremes of chemical and physical conditions were involved. When the warm flood waters crept across the extensive floodplains, a whole new pulse of life occurred that resulted in plant renewal and the triggering of a complex faunal cycle. The millions of microzoa fed the small fish that emerged, and on which birds and other animals fed (Lake 1967). The introduction of dams and weirs has interfered with this natural cycle, but some simulation of it by dam control would be possible. Only 19 species of native freshwater fish live in the vast Murray/Darling R. system, but they show some remarkable adaptions to their unusual habitat. These must have evolved since the present semi-arid climate came. Eight species of fish have been introduced. Rainbow and brown trout do well in the colder upper reaches of the rivers, while redfin and tench do well in the dams.

Conservation of the Ecosystem

The present ecosystem took 2 m.y. to develop, and is very finely adjusted to very unusual conditions. In that period of time many new species have appeared and many became extinct in the study area. The lungfish (*Neoceradotus*) and many marsupials have disappeared from it (Marshall and Merrilees, this *Memoir*). On the other hand, a fossil tortoise found in Fisherman's Cliff, Moorna Station, in Chowilla Sand between the Moorna Formation and the Blanchetown Clay could not be distinguished by Professor J. W. Warren from its living counterpart.

The dry terrain is subject to erosion, but was much more stable before the introduction of herds of sheep and other animals. To conserve the ecosystem requires careful management. The first two years of our study (1967-8) were drought years, and wind erosion was very extensive. However, the incidence of erosion varied from station to station. The examination of the air photos shows the unused or little used areas are much more stable. On the other hand, some areas that were badly eroded have been restored by good management.

The extensive occurrence of Aboriginal middens with charcoal in the topsoil extending back to 2,000 yr ago shows that until recently the surface has kept intact over wide areas for two millenia. As charcoal is one of the most easily eroded materials, its presence is good evidence of undisturbed ground. On the W. side of Lake Victoria, the stratigraphy of the gulches and colluvial fans shows that in the past there have been periods of erosion and periods of infilling (Fig. 47). To delineate these and date them would be a useful project. Active gullying is now in progress, and there is difference of opinion as to when this was initiated. The latest cementation by carbonate is the fixing of the top 10-15 cm of the latest colluvial fans. This indurated layer contains middens, Aboriginal bones, and other dateable materials. A midden of this layer on Noola Station contained carbonized twigs (probably saltbush) that gave a modern reading upon radiocarbon assay. This means that the age is 200 yr at most, so the erosion has occurred since the arrival of Europeans, their sheep and rabbits and their machines.

Water erosion following heavy rain is assisted by the nature of the spoor of sheep and other ungulates. Kangaroos and emus have discontinuous spoor, but sheep scuff the ground with their hooves and excavate a rut down which water rushes, so initiating a gulch. Similarly I have seen rain following the tyre marks of a motor car. Thus the terrain is sensitive to wind and water erosion, necessitating careful management, if it is to be conserved. This is desirable both economically and scientifically. The country has a considerable capacity for recovery.

Aboriginal Ecology

'The earth's surface being to them a book they always read.' Major Mitchell

Having been over 30,000 yr in the country (Bowler *et al.* 1970) the Australian Aboriginals had long become an integral part of the ecosystem by the time Europeans arrived. The Aboriginals were one with their country. It was in character for them to prefer the local opal for their implements rather than the more efficient imported flint 'because it was part of them' (so said Aboriginals in the Western Desert). Natives on the Darling River asked Mitchell to return water he had taken from it. They had totemic relationships with animals in the local fauna. During the long period they inhabited this area, there were changes of climate and many of the local species became extinct. They were a conservative people (keeping to the ancient core/flake culture), but managed to accommodate themselves to these changes. When animals that became extinct were totems, deep-seated mental adjustments were necessary. Economic change was enforced by loss of technological raw materials (bone, skin, hair, tendons, fat, etc.) from the animals that went extinct, plus loss of a food source.

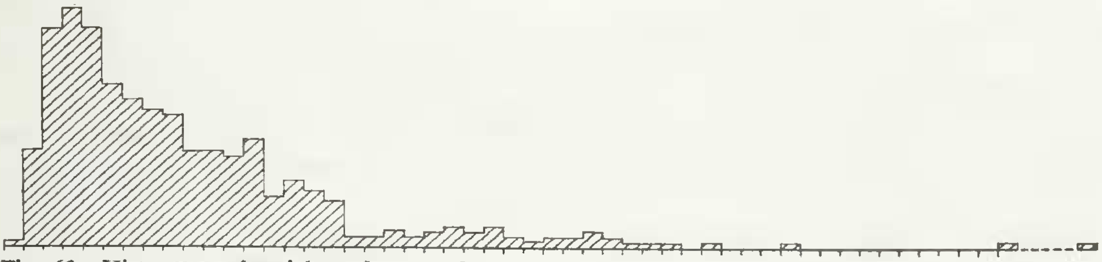


Fig. 63—Histogram of weights of stones from Aboriginal oven in Scrub Paddock at top of hill SW. of Dickie's Gate, and E. of Salt Creek, Kulcurna Station, N.S.W. Site 2. Categories are of 10 grams each, extending from 1-10 to 501-510; then there is a gap, and the final category is 581-590.

Two sources provide information on the way of life of the Aboriginals of this area:

1. *Early explorers and settlers,* Mitchell (1839), for example, described the Darling R. natives, their dress, artefacts (spears, canoes) and something of their daily activities such as hunting marsupials, spearing fish, netting ducks, collecting mussels and roots, using fire, dancing, communicating by calls and fire-signals, and burying the dead. Sturt (1849) described the natives at Lake Victoria and thereabouts. The notes of Beveridge (1865), Hawdon (1852), Morton (1861) and others are likewise helpful. Lawrence (1968) has accumulated valuable background information.

2. *Archaeologic evidence.* In this *Memoir* Casey has described artefacts, Blackwood and Simpson the Aboriginal skeletons, and Sandison their pathology. Many middens have been recorded. From an ecologic point of view, three types of Aboriginal fireplace need to be distinguished:

(a) *The midden.* In this area these consist of mussel shells (*Velesunio*), charcoal, ash and sometimes burnt ground (Gill 1969). The term is derived from a Scandinavian word for a refuse heap, and so is appropriate.

(b) *The oven.* This is a fireplace characterized by cooking stones. These are accompanied by charcoal, ash and sometimes burnt ground. Due to the shortage of rocks in this area, all manner of materials were used. Sandstone, ironstone and pieces of wasps' nests were utilized. Over much of the area, only pedogenic materials were available, such as carbonate nodules and silcrete. Figure 63 shows the size distribution of carbonate nodules in an oven on Kulcurna Station illustrated in Gill 1969, p. 181. The weight analysis is of the oven stones shown in the well-defined round oven area in the foreground of the photograph.

Where no stones were available for ovens, the Aboriginals baked mud lumps for this purpose. It is the nearest they came to making pottery. Impressions that appear to have been made with fingers, or in one instance an arm, have been noted. Barbetti (this volume) has studied the palaeomagnetism of these oven clays. Thermoluminescent tests have also been made on them. See Pl. 10, fig. 3.

In some ovens the stones were a mixture of imported rocks and the baked clay lumps. Mitchell (1839, vol. 2, p. 81) states' 'The common process of natives . . . is to lay the food between layers of heated stones'. Beveridge (1865) described the customs of the Murray R. natives among whom he lived in the Lake Boga area. He said. 'They cook their food by means of red hot clay placed over the bottom and round the sides of a hole prepared for that purpose. Over the hot clay they place a thin layer of damp grass, upon which they lay the joint to be cooked, covering it over also with damp grass, upon which more hot clay is placed, the whole is then carefully covered with sand. It is a very perfect method, and can be made large enough to roast an ox, or small enough to cook an opossum'. Similar methods are still used by some tribes of Aboriginals, e.g. at Yirrkala in N. Australia.

Brough Smyth (1878) stated that the Lower Murray natives 'cook their large game in ovens made in the following manner—a hole is made in the earth and lined with stones; in it they make a fierce fire, until the stones become almost red hot; the kangaroo, or what they intend to cook is then placed in the oven, on the top of which some more hot stones are placed, and the whole covered with earth; the heat of the stones and the confined steam together cook the meat' (Vol. 2, p. 298).

Beveridge's and Brough Smyth's descriptions are important in that they explain that the ovens were used for thick meat. In the lunette on the E. side of Lake Victoria, numerous shell middens are found, and fossil extinct marsupials are also found there, so some have inferred that this proves the Aboriginals did not use these marsupials for food. This in an incorrect inference. It should be noted that the Aboriginals employed two cooking media—the small midden fire for cooking small pieces of meat such as mussels, and the oven, the heat-holding capacity of which permitted the cooking of thick pieces of meat. Only once were bones found in a midden, and that was in the one on the N. shore of Lake Victoria E. of the old hotel site. This contained some bones of the small marsupial *Onchogalea frenata.* Thus, the composition of shell middens is not a guide to what marsupials were used for food.

Unfortunately, no bones have been found in ovens in the study area. It has been noted how the bones of both modern and fossil animals readily decrepitate in this climate when they are exposed at the surface. No bone implements were found by us. Gallus (this *Memoir*) describes two bone fish-hooks associated with a skeleton. Brough Smyth (1878 vol. 1, p. 203) believed them to be absent, so perhaps their use was prehistoric.

Ovens were used by the earliest known Aboriginals, evidence of whose presence has been discovered at Lake Mungo, NE. of our study area (Bowler *et al.* 1970). Burnt clay has been dated there at 30,750 yr B.P. (Anonymous 1972, Barbetti and McElhinny 1972). Dury and Langford-Smith (1970) recorded a fireplace at Lake Yantara in NW. New South Wales that dated 26,200 yr B.P. Judging by the photograph, lumps of burnt sediment were present.

As these pieces of 'brick' could be used again and again, it might be assumed that when rain fell, sediment on site was puddled and burnt. Ecologic analysis shows that in some sites at least this can be proved untrue. Thus ovens on dunes of well-sorted sand have cooking stones made of relatively poorly-sorted sediments from the nearby river.

Finally, it should be kept in mind that clay balls were also used as sinkers (Hardy 1969, p. 12).

c. *The hearth.* This third kind of fireplace has ashes and charcoal only (with burnt ground at times). No shells, bones or cooking stones are present. The localized nature of the deposit and its very close similarity to the middens and ovens shows that it is of Aboriginal origin.

The fireplaces preserved are of course only a fraction of those made. If ten groups of Aboriginals in this area each made one fire a day for 30,000 years, this would amount to about 11,000,000 fireplaces.

(d) *Stone material.* Being over a deep sedimentary basin, the terrain is a stoneless land. Then how did the Stone Age men manage for stoneware? Their light industry (the small tools) was supplied from local pedogenic materials (opal, silcrete, carbonate), while their heavy industry (millstones, mortars and such) were mostly imported from the areas where Palaeozoic and Precambrian rocks from the margin of the basin, viz. the Great Dividing Range to the E., the Barrier and other Ranges to N., and the Mt. Lofty Ranges to the W. A petrological study to define origins (cf. Ambrose and Green 1972, Dixon *et al.* 1968, Glover and Cockbain 1971, Shotton 1968, Sieveking *et al.* 1970) is needed.

Local rocks, even when unsuitable, were tried. Mr and Mrs H. Hansen collected a millstone made of a relatively soft calcareous sandstone, the source of which was probably Pine Camp Station, where it outcrops at the side of a dry lake. The best known local development of pedogenic siliceus sandstone is at Moorna Station homestead where it was used for building. The paleosol that yielded it is now under water, as the river level is controlled in this reach of the river. This rock was utilized by the Aboriginals.

Because all the local rocks are pedogenic materials of a limited range of types, it is easy to recognize the 'stranger rocks' brought in by human agency. It has already been mentioned that the local common opal was used and not the Mt. Gambier flint (Daley 1926), which was traded up to the N. Mallee not far from the Murray R. Only two pieces of flint were found among the many thousands of Aboriginal implements and flakes examined. Tertiary marine fossils were recognizable in them, and Whitehead (this *Memoir*) reports on the application of a new method in an endeavour to prove their origin.

As the Aboriginals brought in by trade silicified sandstone and quartzite for their large implements, it might be expected that they traded out other things such as opal. (On trading see Mulvaney 1967, p. 94 ff., Tindale 1968). However, Sir Robert Blackwood and I as a check collected opal-like material from between Wentworth and Broken Hill; also at Menindee and Mootwingee. Dr E. R. Segnit examined these, but they all proved to be very fine-grained silcrete and not opal. It is known that the Aboriginals traded reed stems from the Murray R. for spear shafts (Gutheridge 1907, Stone 1911).

On the lunette, a yellow Tertiary fossil shark's tooth, *Isurus hastalis*, was found. The nearest formation from which this could come is Miocene limestone that outcrops on the banks of the Murray 150 km to the W.

The range of Aboriginal implements found in the area was a surprise. No pirris (Campbell 1960) or tula adzes (or a few doubtfully) were found although these are the 'two basic prehistoric implement types'. So says Mulvaney (1964) and added that they 'appear inexplicably to observe State boundaries in their occurrence' They were not found in the study area nor in some places examined further N., so in this region the boundary is N. of the State boundary. Mr T. Brown (pers. comm.) of Broken Hill has a good collection but they came chiefly from N. of that town. Rare ground-edge axes and cylcons have been reported, but these uncharacteristic occurrences do not reflect the local material culture, but perhaps strange objects accepted as having magical power. The fact is that the plentiful artefacts of the area demonstrate the primitive core/flake culture, such as characterizes the earliest known Aboriginals.

The distribution of artefacts is instructive. They occur in high concentrations beside Lake Victoria and at sites such as (a) The inland limit of the lunette sand encountered on the Talgarry pipeline track from Lake Victoria to the dams near the homestead. (b) On the same track SW. of the second dam from the road (on the fenceline). Both these sites are in geomorphic lows with sand underlain by clay. After heavy rain, pools of water last up to two months, and even when they have disappeared water is available in the sand. Thus we have a picture of the Aboriginals as river people who moved inland as pool-campers after the rains. Some sites are more than 15 km from the river/lake system.

The Aboriginal skeletons collected (Blackwood and Simpson, Sandison, this *Memoir*) and those seen but not collected, indicate a comparatively healthy people, as far as this can be judged from their bones. Broad based on the productive river/lake ecosystem, they were apparently well fed (mussels, fish, crayfish, turtles, water-fowl, emus, marsupials, plants). In addition, they were conservative, adhering to the ancient core/flake industry, and allowing the new cultures of hafted tools and microliths to go by. They imported only what was necessary, relying on local materials. Their outside contacts were minimal, so limiting the likelihood of infection from elsewhere.

The natives ground nardoo (Howitt 1908, Lees 1915) on their millstones, and used hammerstones on mortars for a wide range of jobs (McCarthy 1967). Canoes were used (Mitchell 1839, Beveridge 1865, Curr 1886) on the rivers and lakes (Mitchell 1839), and 'canoe trees' still remain with the scars (now well overgrown at the edges) whence the bark was removed. Scars left by bark removed by early settlers for tables and such are sometimes confused with Aboriginal canoe trees. We therefore experimented by removing squares of bark from the same red gum with a steel tomahawk and an Aboriginal stone axe of similar size. The former cut sharp narrow deep cuts with sides approximately parallel, while the latter cut shallower burred cuts with curved sides. We found that a sharp stick was also effective.

The reed spear-shafts of the river people were too light for stone heads, so the tips were made from mulga (*Acacia*). Mr J. Higgins (the oldest resident) described how the Aboriginals cut a groove round the mulga branch then cut thick slivers towards the groove, thus obtaining pieces of this very hard wood about the size and shape of the quartzite flakes used elsewhere for the same purpose. We did not know that mulga occurred this far south, but Mr Higgins pointed out two relict patches, one of over 10 hectares and the other with only a few trees.

The literature describes pieces of stone used for various types of magic by Aboriginals. Some formless pieces of imported stone found in the study area are presumed to have had some such use. For example, a flat piece of flakey mica schist from Ned's Corner Station was useless as an implement but its bright golden flecks could well have suggested some innate power to an Aboriginal.

McCarthy (1968) has described coastal and inland sequences of cultures with the Dividing Range between as a barrier. Such barriers are as much psychological (accepted boundaries) as they are physical. Similarly, the Murray River was a barrier. These barriers can be regarded as diffusion lines through which diffusion vectors (usually southwards) operated to bring about cultural change. The Murray R. constitutes a strip ecology surrounded by semi-arid country, so it is a natural interface, and tribal boundaries were related to it. Tindale (pers. comm.) states that the Maraura tribe lived to the N. and the Ngintait tribe to the S. The Maraura controlled the opal mines, and this is probably why large lumps are often found N. of the river but only small pieces in smaller quantity S. of it. N. of the Murray R. were quartzitic millstones and mortars, pirris, tulas, flake knives and picks, stone-tipped spears, bull-roarers, cylcons, carved trees, copi grave markers and so on. To the S. were basalt mortars, flint artefacts, wooden spears with hardened tips, and so on. However, in our study area only the large flat millstones appear to have the Murray R. as an actual limit of distribution. They are common N. of the river, but of negligible occurrence S. of it.

In review, one is amazed that in spite of the changing ecology (climate, fauna, etc.) there was a technological stability that lasted in this area for some 30,000 years. In spite of this, the Aboriginals of the area readily took to European meats, tomahawks, knives, blankets, and so on (Mitchell 1839).

Economic Considerations

The soil is this country's greatest wealth, so it needs conservation. Some of the world's finest wools are grown in this semi-arid country. Water is the limiting factor. In the dry summer time, especially in drought, the terrain appears harsh, but when the heavy rains fall, a miracle of regeneration is re-enacted. The perennials spring up with amazing rapidity and in six to eight weeks mature and seed. As the irrigation areas prove, this land is most productive when water is available.

South of the Murray R., the dominance of sandy terrain results in losses of up to 90% of the water passed through the feeder channels. N. of the river the Blanchetown Clay (below the veneer of sand) permits the excavation of earth tanks to preserve run-off water. The Darling R. is the local Nile in that it begins in a humid zone then flows 2,500 km and more through dry country. The clay floor and banks preserve its waters which are not supplemented by tributary streams.

On this semi-arid terrain there is one sheep to 2·5 hectares (6 acres) or more. The large woolshed of the Lake Victoria station has processed up to 98,700 sheep at one shearing (32 stands). Some cattle are raised along the rivers and lake shores. Cattle require fresher water than sheep which will drink water with up to 7,000 ppm (weight), i.e. about one fifth the salinity of the sea.

The water table in this area is very low. Piezometer bores in connection with the Chowilla Dam (data kindly made available by Gutteridge, Haskins and Davey) proved oxidation from the general land surface about 37 m above the river up to 12 m below river level, and up to 8·5 below water level in August 1968. The pH of the groundwater varied from 7·1-8·3. Sodium and chloride constituted 77·1% of total salts. Water from all the bores (traverse lines across the Murray R. from the

S.A. border to Mildura) had much the same ratio of salts.

The salinity of groundwaters and river waters has been a major problem. During the drought of 1967 the River Murray Commission contracted Gutteridge, Haskins and Davey in association with Hunting Technical Services Ltd. to study this matter and in 1970 three volumes were published, viz. 1. The Report, 2. Maps, and 3. A Summary. These volumes define the amount of salt involved, and its effects under the varying conditions obtaining in that area from time to time. The Report indicates the need of further research and the importance of adequate management.

Salt is harvested at Lake Tyrrell. Papers on salinity in the Murray region include Anonymous 1968, Crabb 1968, Hutton 1958, 1969 and references, Livermore 1968, McLaughlin 1966, Penman 1969, Williams 1970. Papers on underground water include Barnes 1951, Gibbons *et al.* 1972, Lawrence 1966, Macumber 1968, O'Driscoll 1966 and references.

Gypsum has been worked commercially in the study area. Timber is gained, chiefly river red gum. Commercial fishermen operate along the Murray R.

Beds of dolomite are reported for the first time in this area, but at present there is no commercial use for it.

Conclusion

This virtually unknown piece of country has proved to have rich geologic, archaeologic and biologic histories. The present reconnaisance, reported here inadquately under pressure of time, is but an indication of what has yet to be discovered. There are so many obvious worthwhile research projects and I am so often asked for suggestions, that I append a list.

APPENDIX 1

List of Maps

Military maps 1" = 4 mi.	Renmark, Chowilla, Mildura, Anabranch.
Fire maps	Wentworth.
Photo maps	Lindsay, Wentworth, Mildura.
E.W.S.	1–6.
Air photos	Lindsay, Wentworth, Lake Victoria.

APPENDIX 2

Research Projects

1. Relationship of stream direction to tectonics.
2. The system of exceptionally fine-grained fluviatile, lacustrine, beach and dune sediments..
3. Age and evolution of Lake Victoria.
4. The Boy Creek/Wallpolla Creek anabranch system.
5. The remarkably extensive meander belts.
6. The age of the major oxbows as shown by radiocarbon dating of their basal sediments.
7. The origin of mottled profiles below present base level (e.g. Moorna East oxbow lake).
8. Analysis of meander lengths of the present and the past.
9. The differences in lithology and pedology N. and S. of the Murray River in the study area.
10. Origin of depressions (such as hold salt lakes) in the flat plain.
11. Stratigraphy of Salt Lake on Talgarry Station to follow its origin and history, dating by radiocarbon.
12. Relationships of E-W. longitudinal dunes (Woorinen Formation) with other formations (e.g. Rufus Formation), and with the various levels of Murray River incision.
13. Dunefield history, and the nature of the depression of dune forms in each stability phase, marked by near horizontal soils.
14. Differences between Mallee and Lake Victoria Dunefields, and the reasons therefor.
15. The relationship between Lowan Sands and the Mallee E-W. Dunefield.
16. The relationship of the present Lake Victoria to the basin in which it lies.
17. The gulches in the lunette on the E. side of Lake Victoria (which present extensive stratigraphic, pedologic, sedimentologic, archaeologic and palaeontologic data).
18. The facies of the Lake Bungunnia deposits, and their palaeogeography.
19. Survey the Triple Swamp cliffs, Fisherman's Cliff, and the cliffs of Moorna E. oxbow lake (which are nearly continuous) to provide a detailed section many kilometres long that would elucidate the lateral variation and interdigitation of formations in this area.
20. The Rufus Formation, its character and extent. It offers the opportunity of discovering any significant change in the Murray R. tract and the Lake Victoria basin since the ? Middle Pleistocene. Also its relationship to ancestral and prior streams.
21. The Monoman Formation, its distribution upstream, and its relationship with the ancestral and prior streams; also with change of sealevel.
22. Systematic C14 and other dating of paleosols in the Lake Victoria lunette and the E-W. dunes (Woorinen Formation) to define the periods of stability (soil-forming) and instability (dune-building) on this terrain. This would constitute a valuable contribution to palaeoclimatology.
23. Along with 22 or as a separate project to carry out grids of grain size analyses to discover (a) the degree of consistency in the sediments and (b) whether certain types (e.g. bimodal) can be